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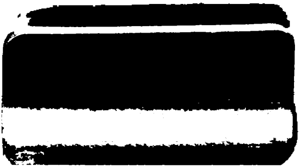

A

MANUAL

OF THE

STEAM ENGINE

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ENGINE OF THE RUBY STEAM VESSEL.

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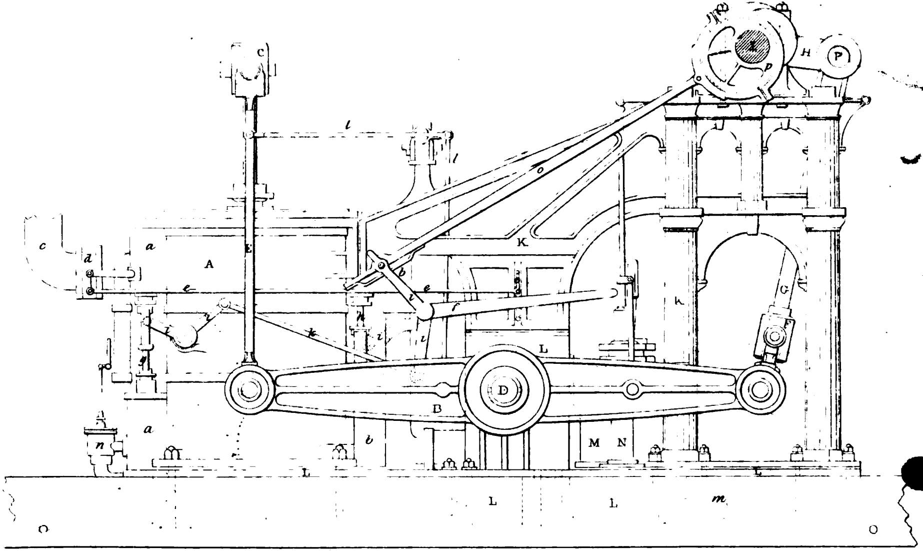

A
MANUAL
OF THE
STEAM ENGINE

BY

RICHARD D. HOBLYN A.M. Oxon.

AUTHOR OF A
"DICTIONARY OF TERMS USED IN MEDICINE AND THE COLLATERAL SCIENCES"
AND OF "A MANUAL OF CHEMISTRY"

Illustrated by numerous Engravings on Steel and Wood

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PREFACE.

It can hardly be imagined that any one in the present day can be indifferent to the subject of *Steam Power*, especially in its application to *locomotion*. A difficulty, however, occurs to many persons desirous of becoming acquainted with the principles of this discovery, from the intricate calculations, frequently of a mathematical and algebraical character, which are found in the more comprehensive treatises on the *Steam Engine*. It occurred to the author of the present work that, without entering into the details of abstract research, the general application of chemical and mechanical science to the operations of steam power, might be explained in a manner sufficiently *popular* to give the reader an immediate interest in the subject, and to stimulate him to pursue the inquiry by the perusal of more elaborate and systematic works. How far he has succeeded in his object must be left to the reader to determine.

In following out the plan, above indicated, it appeared desirable to proceed at once *in medias res*, and to illustrate each principle of science by direct reference to its bearing upon the machinery and operation of the steam engine. A short *preliminary chapter* is given, explanatory of some of the immutable properties and laws to which matter is subjected. The doctrine of what is

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termed Latent Heat, the influence of Atmospheric Pressure, the Elastic Force of Steam, the Principles of the Condensation of Steam and of the consequent production of a Vacuum, together with the application of these agencies in developing Mechanical Force, as a *moving power*, are briefly sketched. The reader who is already acquainted with these principles, may pass over this preliminary matter, and refer to it as occasion may require.

In the *second chapter*, the Rise and Progress of Discovery, together with the early Applications, of Steam Power, are traced up to the era of Smeaton, in 1772. The ingenious toys of Hero, the wheels and pestles of Branca, and other contrivances invented at this early period, will afford amusement to the searcher after antiquarian curiosities. Mechanical apparatus in the form of wings, and of chariots, for excursions to the moon; machines for the continual utterance of "sweet sounds" by means of mills and of fire; engines for the different objects of rocking cradles and of turning spits; instruments for effecting perpetual motion;—these, and numerous other torturings of ingenuity mark this characteristic period in the annals of science and art. But in the profounder researches of Lord Worcester and Sir Samuel Morland, and in the extension and development of chemical and mechanical science by Papin, Savery, and Newcomen, we are enabled to trace all the rudiments of a perfect engine, requiring only the talismanic touch of a master spirit to arrange the *disjecta membra*, and to produce at once symmetrical organization and harmonious action. Tredgold well observes,—"Our imperfection consists generally in not being able to foresee all the circumstances which have an influence on the effects of causes; but in proportion as we proceed in knowledge, we also acquire greater powers of perception: that which was at first difficult becomes easy, and the mind is often roused by the bright gleam of truth, breaking as it were accidentally upon a mass of obscure ideas, and rendering the true solution of the difficulty at once obvious; and, as my gifted countryman Emerson has remarked, 'the labour and fatigue of seeking after it instantly vanishes.'"

The *third* and *fourth chapters* are devoted to the *Era of Watt.* The boyish fabricator of 'candle-bombs,' the cutler and whitesmith, the maker of compass legs, the repairer of fiddles and fishing tackle, the tuner of spinets, the retailer of nick-nacks of various kinds, the spectacle-maker, yclept optician, who "jobbed on his own account" at Greenock and at Glasgow;—this man, with acquirements not beyond the limited knowledge necessary for the business of a surveyor, indolent from weak health, procrastinating from an active but desultory imagination, possessed of little curiosity even on subjects which might have been considered vitally essential to his interests, absolutely insensible to fame and undisturbed by mercantile ambition, yet, with all this, of a fertile and exquisite invention (Stewart)—this man *still lives* as the Inventor of the modern Steam Engine. In his hands the *atmospheric engine* of Newcomen immediately became a *steam engine;* "from the first," he observed, "I intended to operate with steam instead of the atmosphere, and my apparatus was so constructed." The labours of Watt were successfully devoted to the completion of the Single, and the Double Acting Steam Engine, the latter of which is at the present day employed, with certain modifications, for the purposes of Steam Navigation. The *details of the machinery* composing these engines are illustrated separately, and in their combined capacity. A concise, but sufficient, description is given of the *essential parts* of the engines, viz. of the boiler, the cylinder, the condenser, and the air-pump, and of their relations to each other; of the modes of *equalizing the action* of the engines, as by counter weights, by fly-wheels; of the methods of *regulating the power* of the engines, as by valves, by governors; of the nature and operation of crank motions; of the mechanical combination for producing the parallel motion; and of other particulars.

In the *fifth chapter*, the mode of employing steam by *expansion* is explained. The economical application of this principle is pointed out, with reference to its introduction by Watt, and to its adaptation by Hornblower and Woolf to certain modifications of the machinery of engines. This chapter concludes with a description and illustration of the ingenious engine of Cartwright.

In the *sixth* and *seventh chapters*, the various parts of the modern steam engine are considered *separately*, preparatory to the consideration of them in their combined condition, and in their relations to each other, in subsequent chapters. Some preliminary remarks are made on the laws of *combustion*, on the effect of *fuel* in producing steam, and on the modes of measuring the pressure, or tension, of steam. These chapters are then devoted to the consideration of the construction and proportion of the several parts of the steam engine, as of the safety apparatus; of the boilers, with the precautions necessary for their safety and effect; of self-regulating furnaces; of cylinders and pistons; of valves, with reference to their form and mode of action; of the mechanism by which the valves are worked; and of the apparatus for indicating the pressure of the steam in the boiler. Appropriate illustrations are given of all these parts in their separate capacities.

In the *eighth chapter*, some remarks are made on the *mechanical power of steam.* Under this head, the several methods of developing power from steam are noticed, with reference to the machinery described in the preceding chapters. The relations existing between the pressure, temperature, and density, of steam, and the application of these laws to the experiments and theory of M. de Pambour, are pointed out. The chapter concludes with some observations on the *duty*, and the *power*, of steam engines.

The *ninth chapter* is devoted to a succinct account of *Locomotive Engines on Railways.* The subject comprises the early history of the invention, with the ingenious but abortive contrivances for locomotion, by which that period was characterized; and the recent history of locomotive engines on railways, dating from the time of the "Liverpool Experiments," and extending to the newest improvements of the present day. The subject is illustrated by an elevation and sectional views of a modern engine. Some remarks are added on the construction of *railroads*, the resistance produced by friction, and the effect of gradients. The chapter concludes with a few extracts from the Parliamentary Report on Gurney's Steam Engine, as adapted for common roads.

The *tenth chapter* is devoted to the subject of *Steam Navigation.* Its early history is briefly traced. The differences which occur in the machinery and modes of action of the land and of the marine engine, and the relations which subsist between the several parts of the latter, are described and illustrated. A comparison has been drawn between the common injection engines, and those fitted up with Mr. Samuel Hall's patent condenser; and some facts are added from Parliamentary Reports with reference to the performance of vessels furnished with the two kinds of condenser. The various forms of *paddle wheel* which have been successively introduced, afford an interesting proof of the efforts which have been made to obviate the difficulties of propulsion in a liquid medium. The combined machinery, and its mode of operation, are illustrated by a complete view of a marine engine, accompanied with appropriate descriptions. Some observations are added on the mode of propulsion by means of the *Archimedean Screw*, and on the performance of some vessels fitted up with this machinery. The best proportion of *power to tonnage*, required for the useful effect of steam vessels, is a subject of considerable interest, with reference to the extension of steam navigation to remote parts. The chapter closes with some remarks on steam navigation in America.

To expatiate on the *importance* of the subject of steam power, in reference to its influence on the relations of society, would be superfluous. To "annihilate both time and space"—the object of the poetic visionary—may, in a restricted and sober sense, be already reckoned among its exploits; its capabilities are boundless; its results incalculable.

2, *Sussex Place, Regent's Park,*
February, 1842.

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CHAPTER I.

PRELIMINARY OBSERVATIONS ON HEAT AND STEAM.

1. *General Effects of Heat upon Bodies.*—One of the most general and obvious effects of Heat, is *expansion:* all bodies when heated expand, or increase in bulk, and on cooling they contract, or return to their original dimensions. Solid bodies expand much less than those which are liquid or gaseous, and are consequently not employed as a moving power for the purpose of transport Liquid bodies present several phenomena on the application of heat, of sufficient importance to qualify them for locomotive purposes; the expansion of water, for instance, is forty-five times greater than that of iron. Gaseous bodies expand much more by heat than liquids, their particles being in less intimate union, and less under the influence of cohesive attraction; the expansion of air, for instance, is eight times greater than that of water. Bodies which undergo expansion by heat, undergo also an *increase of temperature;* and as these two effects are always simultaneous, the one has been adopted as a measure of the other. Upon this principle is constructed the common *thermometer*, which is merely an instrument for measuring degrees of temperature by their effect in the expansion of some liquid body. It consists of a glass tube with a bore of very small and regular calibre, having a bulb blown on its extremity; the bulb and part of the tube are filled with mercury, this metal being the most uniform in its expansion at all temperatures. By boiling the mercury, the air is expelled from the rest of the tube, the extremity of which is then hermetically sealed. A scale marked with degrees is attached to the tube, and the variations of tem-

perature are indicated by the expansion or ascent, by the contraction or descent, of the mercury; and these can be ascertained by simple inspection of the scale. Of the degrees of the scale, there are two which, under certain circumstances, always present the same phenomena; these are the *freezing* and *boiling points* of water, all the intermediate degrees being arbitrary divisions of the space between these two fixed and unchangeable points. In *Fahrenheit's* thermometer, which is employed in this country, the intermediate space between the freezing and boiling points of water is divided into 180 parts or degrees, the freezing being marked 32°, and the boiling 212°. This scale was adopted from an erroneous idea that 32 of these degrees below the freezing point of water, which is therefore marked 0 on this scale, indicated the *zero*, or greatest degree of cold. On discovery of the error, a series of descending degrees was added below the zero point, having the sign —, or minus, prefixed to them. The *Centigrade* thermometer was constructed by Celsius, and is employed in France; it consists

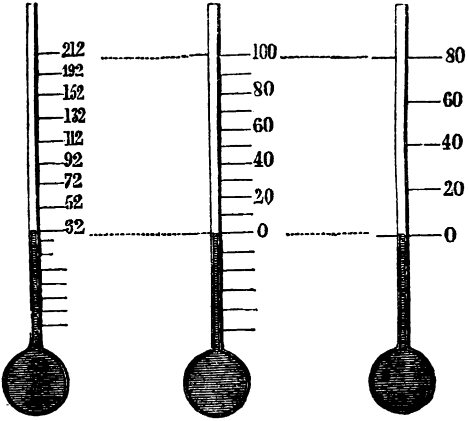

Fig. 1.

in an arrangement of the scale, in which the freezing point is marked 0, or *zero*, and the boiling point 100°. In *Reaumur's* thermometer, which is employed in the north of Germany, the freezing point is marked 0, or *zero*, and the boiling point 80°. The degrees are continued of the same size below and above these points, those below being reckoned negative. A figure is added in the preceding page, showing the correspondence of the three thermometers with each other. These different modes of graduation are easily convertible: the Centigrade scale is easily reduced to that of Fahrenheit by multiplying by 9, and dividing by 5; that of Reaumur to that of Fahrenheit by dividing by 4 instead of 5; or that of Fahrenheit to either of the others, by reversing the process. Thus:—

Cent. 100° × 9 = 900 ÷ 5 = 180 + 32 = 212° Fahr.
Reaum. 80° × 9 = 720 ÷ 4 = 180 + 32 = 212° Fahr.

Or, by reversing the order:—

Fahr. 212° — 32 = 180 × 5 = 900 ÷ 9 = 100° Cent.
Fahr. 212° — 32 = 180 × 4 = 720 ÷ 9 = 80° Reaum.*

2. *Sources of Steam Power.*—The natural phenomena by which the Steam Engine becomes a moving power, are few and simple. They consist in the mechanical forces produced:—1, *by the expansion of water into steam ;* 2, *by the elastic force of the steam thus formed;* and 3, *by the reconversion of steam into water.* Water is capable of existing in the solid state as ice, in the liquid state as water, and in the vaporous state as steam. These changes of state depend upon varieties of temperature and atmospheric pressure; and they are connected with certain phenomena which must be generally explained, before their application to the Steam Engine can be understood. They may be studied in the following order:—

---

* This, and several other paragraphs of the present chapter, are taken from the first chapter of the Author's *Manual of Chemistry*, to which the reader is referred for further information on the nature of *Heat.*

1. *Melting of Ice : Latent Heat.*
2. *Boiling of Water : Latent Heat.*
3. *Influence of Atmospheric Pressure.*
4. *Pressure of Fluids in every direction.*
5. *Elastic Force of Steam : High-Pressure Steam.*
6. *Condensation of Steam.*
7. *Production of a Vacuum.*
8. *Mechanical Force produced by the preceding operations.*
9. *Economical Applications of Heat.*

3. *Melting of Ice : Latent Heat.*—If a mass of ice be introduced into a warm room, and a thermometer be applied to it, the temperature of the ice will continue to rise, till the thermometer stands at 32°; it there remains stationary, although heat is continually entering into the melting ice, as before; and it will remain so, until the whole of the ice is melted. The heat which is absorbed by the ice during the change from the solid to the liquid form, is termed insensible or *latent*, in consequence of its not affecting the thermometer. The amount of heat which is absorbed and becomes latent, in this process, may be estimated by the time during which the thermometer remains stationary; it will be found to be a hundred and forty times as long as the time required to raise the water, in the liquid state, one degree. The quantity of latent heat therefore, of water, is 140 degrees; or, in other words, the difference between a pound of water at 32°, and a pound of ice at 32°, is, that the former contains, in a *latent* state, as much more heat than the latter, as would suffice to heat another pound of water a hundred and forty degrees.—The heat which is latent in water, is liberated and rendered *sensible* when the water is reconverted into ice; this may be proved in the following way. Water may be cooled down many degrees below 32° without freezing, provided it be kept perfectly still; it has been cooled as low as 5°. If it be cooled down to this temperature, and a tremulous motion be then communicated to it, congelation is determined, a large portion of it is suddenly converted

into ice, and the latent heat is liberated in such quantity as to raise the temperature of the whole mass suddenly to 32°.

4. *Boiling of Water: Latent Heat.*—So soon as the entire mass of ice is melted, the thermometer continues to rise until it has reached the temperature of the room. If heat be now applied to the water, by means of a lamp, a thermometer placed in it will gradually rise until it reach the temperature of 212°, and no addition of heat will raise it a degree higher, provided the water be in an open vessel. A new process now begins: bubbles are formed at the lower part of the vessel, rise to the surface, and escape with commotion in the form of *Steam.* This constitutes *ebullition*, or the boiling of water. Steam, as it rises from water at 212°, exhibits the same phenomenon as occurs in the conversion of ice into water at 32°: a quantity of heat is absorbed which serves only to change the *form* of the body, in this case converting water into steam, as in the former it converted ice into water,—in both cases being termed insensible or *latent.* A much larger quantity of heat is absorbed during the formation of steam from boiling water, than during the melting of ice; its amount may be estimated, as in the former case, by the time during which the thermometer remains stationary at 212°; it will be found to be five and a half times as long as was required to raise the water from the freezing to the boiling point, that is, to raise it 180 degrees. Thus, if the application of heat from a lamp were required for one hour, in order to raise a quantity of water from 32° to 212°, it will require the application of the same heat for five hours and a half, in order to convert the whole of the water into steam. The product of these numbers is 990. The latent heat of steam is therefore estimated, in round numbers, at 1000 degrees; or, in other words, sufficient heat is absorbed, during the formation of steam, to raise the temperature of an equal quantity of water a thousand degrees. When steam is reconverted into water, the latent heat is liberated and becomes *sensible.* Hence, a gallon of water, in the form of steam, when added to cold water, will impart

more heat to it, than a gallon of water at the same temperature as the steam; one part of water, for instance, at 212°, will raise the temperature of 100 parts of water at 50°, only one degree and a half, whereas one part of water in the form of steam will raise 100 parts of water as high as eleven degrees.

5. When *Sea Water* is employed, the boiling point varies in consequence of the greater density of saline water than that of pure water, and the force of the steam varies accordingly. Sea water contains 3½ per cent. of saline matter, of which common salt, or chloride of sodium, constitutes the largest ingredient. Now, as the saline matters do not rise with the steam, the water in a boiler supplied with sea water becomes gradually more saturated, and after a certain time begins to deposit salt, sometimes to the detriment of the boiler. Considerable difficulty has arisen in applying the steam engine to the purposes of marine transport, from the necessity of supplying the boiler with sea water, instead of fresh water. During the first trip of the City of Edinburgh steam ship to Leith, in 1821, the deposit of salt was so considerable as to require its being cleared out during the passage, while the vessel proceeded under her canvas. This circumstance induced the manufacturers of the machines, to adopt a method of removing the saturated water from the lower part of the boiler, by means of a pump, and subsequently by means of blow-off pipes and cocks, as is now generally adopted. The boiling point of water appears to rise one degree for each addition of 2·6 parts to the proportion of common salt in 100 parts of water, or very nearly so. Thus, the boiling point of sea water, supposed to contain 3·03 per cent, by weight, of saline matters, is 213·2; if the saline matters amount to 6·06, the boiling point is 214·4; and so in proportion. When the proportion of saline matter amounts to 36·37 per cent., the solution is saturated, and the boiling point rises as high as 226°. The variations in the force of steam generated from salt and from fresh water, are noticed at page 11.

6. *Influence of Atmospheric Pressure.*—The temperature at which steam is formed, depends on the degree of *Atmospheric Pressure* to which the water from which it is formed is subjected. The Atmosphere is supposed to extend about forty-five miles in height around the earth; and it *presses*, under ordinary circumstances, with a weight of fifteen pounds on each square inch of the surface of the earth, and of all bodies upon it. We accordingly find that water boils at lower degrees of temperature, as we ascend higher from the surface of the earth, the pressure of the atmosphere being greatest at the level of the sea. An ascent of 530 feet causes the boiling point of water to be lowered one degree of temperature; at an elevation of 2·705 miles from the surface of the sea, the atmosphere loses half its density, or one volume is expanded into two volumes; the density is again halved for every 2·7 miles of additional elevation. When it is said that water boils, or, what is the same thing, that steam is formed, at 212° Fahr., it is always understood that the atmospheric pressure is equivalent to a weight of 15 pounds on every square inch, or to that of 30 inches of mercury, as indicated by the barometer. For every inch by which the barometer varies from this height, the boiling point of water varies 1·76 degree. The following are the variations between the atmospheric pressure as indicated by the inches of mercury in the barometer, and the boiling point of water:—

Inches of Mercury in Barometer	Water boils at
27·74	208°
28·29	209°
28·84	210°
29·41	211°
29·8	212°
30·6	213°

When *two or more atmospheres* are spoken of, the term signifies multiplied pressures of air arising from condensation. If a mercurial column of 30 inches in height presses upon a given surface with the same weight as the atmosphere in its ordinary state, it follows that a 60-inch column is equal to a pressure of two atmospheres, 15 inches to half an atmosphere, and 1 inch to one-thirtieth of the atmospheric pressure. The influence of the atmospheric pressure on the formation of steam may be readily proved by removing the pressure altogether, as by means of an air pump. Liquids boil in a *vacuum* at a temperature of about 145 degrees below their usual boiling point. If hot water, with a thermometer in it, be placed under the receiver of an air pump, the water boils, and the temperature falls, as the air is being exhausted; as the water receives no heat from without, a portion of its sensible heat is employed in effecting the change of form. Water boils in a good vacuum at 67°. The heat of the hand is sufficient to make water boil in a vacuum, as is exemplified in the common pulse glass. In the absence of an air-pump, the same principle may be illustrated by a simple experiment. Some water is made to boil in a glass flask over a lamp; the flask is then closed with a cork, while the upper part is filled with steam, and it is removed from the lamp. When the boiling has ceased, it may be renewed on plunging the flask into cold water, and the colder the water is, the brisker will be the ebullition. On removing the flask from the cold water, and plunging it into warm water, the boiling again ceases; it may again be renewed on again immersing the flask in cold water. In this experimeut, the boiling ceases on corking the flask, owing to the pressure exerted by the confined steam on the surface of the water; on plunging the flask into cold water this steam is condensed, and the water again boils under the diminished pressure; on immersing the flask in hot water, the steam is no longer condensed, and by its pressure it again prevents the boiling of the water.

7. *Pressure of Fluids in every direction.*—There is another property by which air, and other elastic fluids, are distinguished, and which is important in the action of the Steam Engine: they *transmit pressure equally in every direction.* 1. If a vessel, of a cubical foot in capacity, be supposed to be filled with atmospheric air, the *elasticity* of the particles of the fluid is such, as to press upon every

square inch of the bottom, the sides, and the top, of its inner surface, with a force amounting to a weight of fifteen pounds ; this pressure being quite independent of the *weight* of the air. Hence the lateral, oblique, and upright pressures of air, arising from its elasticity, are equal in amount to the downward pressure of the entire weight of the atmosphere. 2. This elastic property of air varies with the increase and decrease of the capacity of the containing vessel, and in an inverse ratio. If one cubic foot of air be introduced into a vessel of two cubic feet in capacity, the amount of pressure in every direction is halved ; if the cubic foot of air be compressed into a vessel of the capacity of half a cubic foot, the amount of pressure will be doubled. 3. The elastic property of air may be readily illustrated by means of the common *barometer*. This instrument is merely a tube containing mercury, having its open end inverted into a small reservoir containing some of the same metal. The pressure of the atmosphere upon the mercury in the reservoir supports, under ordinary circumstances, a column of 30 inches of mercury in the tube. The space above the mercury in the tube is a *vacuum*. If a portion of air be admitted into this space, it presses by its elasticity upon the mercury, which continues to descend in the tube until its pressure, together with the weight of the mercurial column remaining in the tube, be supported by the weight of the atmosphere. By pursuing this experiment, the elastic force of a small portion of air confined in a tube, is balanced against the entire weight of the whole atmosphere. The elastic force of the air may thus be exactly ascertained : for every two inches of mercury which are expelled from the tube, the amount of the pressure of the enclosed air is one pound, or very nearly so, the weight of two cubic inches of mercury being exactly 15·68 oz., or 0·98 lb. 4. The elasticity of air increases with its *temperature ;* the more heat, therefore, which is applied to any air or gas confined in a vessel, the greater will be the pressure on every part of its interior surface.

8. *Elastic Force of Steam.*—Steam is a vapour consisting of particles of water, which, though of no higher temperature than the water from which it is formed, occupies a space about 1700 times greater than they occupied when in the liquid state; hence a *cubic inch* of water becomes nearly a *cubic foot* of steam, at 212 degrees of the thermometer, and under the common pressure of the atmosphere; and the elastic force of the steam is equal to the pressure of the atmosphere under which it is formed. But when steam is confined, and thus subjected to additional pressure, it rises in temperature and acquires great elastic force; it is then called *high-pressure steam.* The greater the pressure, the more elevated is the temperature required to produce vapour, the denser is the vapour produced, and the greater its elasticity. At 212°, the barometer standing at 30 inches, steam has sufficient elasticity to overcome the atmospheric pressure, and rise against it. The elasticity of steam still in contact with water, increases in a greater ratio than the temperature at which it is produced: thus, at 212° it is equal to one atmosphere; at 250·5, to two atmospheres; at 293·7, to four; at 341·78, to eight; at 398·48, to sixteen; at 435·56, to twenty-four. To this rapidly increasing elasticity are owing the frequent explosions of vessels not provided with safety valves.—The *elastic force of steam*, when heated under pressure, may be illustrated by the annexed figure, which represents a stout copper vessel, of a globular form, called a *Papin's Digester*. It contains some mercury *m*, and some water *w;* and a long glass tube *t t*, open at both ends, is fastened into it, the lower extremity dipping into the mercury, and the upper part being furnished with a scale *a*, divided into inches. There are two other openings in the vessel; into one of these

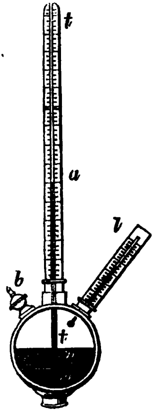

Fig. 2.

a stopcock *b* is screwed, and into the other a thermometer *l*, the bulb of which is within the vessel. Heat is applied, the stopcock being open, until the water boils. On closing the stopcock, and continuing the heat, the temperature within rises above 212°, as indicated by the thermometer. Steam continues to be formed, and, becoming denser, forces the mercury up in the tube *t t* to a height proportional to the elastic force of the steam. The weight of the atmosphere being equal to a column of mercury of 30 inches, this pressure has been overcome by the steam at 212°, before the mercury began to rise in the tube *t t*. For every thirty inches, therefore, which the mercury rises in this tube, the steam is said to have the elastic force of another atmosphere. Thus, if the mercury rise 30 inches, the elastic force of the steam is that of two atmospheres; if it rise 45 inches, it is that of two atmospheres and a half; if 60 inches, of three atmospheres; and so on. The force of steam varies, however, when generated from *fresh*, and from *salt*, water. According to Watt, at 180°, the force of pure water is estimated at 14·73 inches of mercury, that of salt water at 10·85; at 212°, fresh water has a force of 29·56, salt water only of 22·74 inches.

9. *Condensation of Steam.*—It has been stated, that during the formation of steam from water at 212°, and under the ordinary atmospheric pressure, 1000 degrees of heat are absorbed, which serve merely to change the *form* of the body; and that, as a consequence of this, one cubic inch of water expands into 1700 cubic inches of steam. We should, therefore, expect that, upon withdrawing this heat, the form of the body would again be changed, or, in other words, that the steam would be *condensed* into water. And such is the case. When any body which is colder than steam is brought into contact with steam, the latter gives out its latent heat, till the temperature of the cold body becomes the same as that of the steam, or till the whole quantity of steam is condensed to a degree of elasticity corresponding to the tem-

perature to which the cold body is raised by the heat of the steam. In order to produce effective and rapid condensation, several circumstances are required, viz., a large quantity, a great degree of coldness, and a rapid conduction of heat, of the cold body employed for condensation. The greater the quantity of the cold body, the less will its temperature be raised; and the colder it is, the more will the elastic force be reduced; hence, in order to reduce the elastic force of steam as low as possible, the quantity and coldness of the cooling body should be as great as possible. The most effective cooling body for condensation, is *water*. Its operation may be illustrated as follows. If the cubic foot of steam, formed from the cubic inch of water at 212°, as already described, be received into a vessel which just contains it, and 5½ cubic inches of water at 32° be injected into the vessel, the steam will immediately communicate its latent heat to the cold water, and will itself return to the liquid form. The vessel will then be found to contain 6½ cubic inches of water at 212°; of these, 5½ have been raised from 32° to 212°, by the latent heat of the steam, and the remaining inch retains the temperature which it had when in the form of steam. These results agree with those above described, as taking place in the production of steam from water (p. 5). In order to convert a given quantity of water at 212° into steam, it required 5½ times as much heat as was required to raise the same quantity of water from the freezing to the boiling point. Reversely, during the reduction of steam to water, the former parts with as much heat as is sufficient to raise 5½ cubic inches of water from 32° to 212°; that is, 5½ times 180°; that is, 990°, or the latent heat of steam.

10. *Production of a Vacuum.*—The condensation of steam, just described, is obviously attended by the important result of producing a *vacuum*. A cubic foot of steam contains 1728 cubic inches; when this quantity of steam is condensed, one inch of water is found in the containing vessel,

while 1727 inches of it remain unoccupied; in other words, the vessel, with the exception of one cubic inch of water, presents a vacuum. This may be illustrated by a simple experiment. If a little water or ether be put into a glass tube, open at one end, and blown into a bulb at the other, and the bulb be held over the flame of a candle, the liquid will boil, and the steam issue copiously from the tube. If the tube be now inverted, and its open end be plunged under cold water, the steam in the tube will be condensed, and the water will be forced up suddenly into the tube, and fill the bulb. It is a law in physics, that, when a vacuum is produced, the surrounding bodies have a tendency to rush into it with a certain force. The production of a vacuum becomes, therefore, a source of considerable mechanical power.

11. *Mechanical Force produced by the preceding operations.*—The application of the foregoing principles, as a moving power in the Steam Engine, may be illustrated by a little instrument contrived by Wollaston. It consists of a glass tube, which is enlarged at one end into a bulb, and is open at the other. A piston *p* is fitted to this tube, so as to move up and down with ease, but at the same time to be air-tight. Some water is put into the bulb, and heated; steam is formed, and the piston is raised to the top of the cylinder. In this case, *the elastic force of the steam* is the moving power, and this force is proportionably greater, as the piston is more loaded, and the steam more confined. If the bulb be now plunged into cold water, the steam in the cylinder is condensed, and a vacuum is produced below the piston, which is now forced down to the bottom of the cylinder by the pressure of the atmosphere. In this

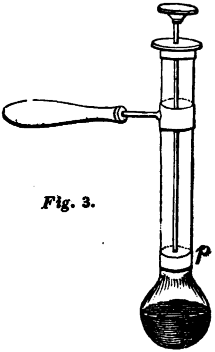

Fig. 3.

case, the moving power is acquired by *the condensation of the steam*, and the consequent production of a vacuum; and this is the principle of the common condensing engine. The *amount* of mechanical force which may be produced by the foregoing processes, may be easily estimated. 1. Let us suppose the water A in the tube A B, in the adjoining figure, to occupy the space of a cubic inch, and the surface of the piston P to be an inch square; if the weight of the piston be exactly counterbalanced by a weight W acting over a pulley, it is evident that the force of the atmosphere alone will act on the upper part of the piston, and that this force will be equal to a weight of fifteen pounds. It has been already stated that a cubic inch of water expands into 1700 cubic inches of steam; hence, the piston would be raised this number of inches in the tube, provided the latter were of sufficient length; or, in other words, *the mechanical force produced by the evaporation of a cubic inch of water is sufficient to raise a weight of fifteen pounds to a height of* 1700 *inches, or* 142 *feet.* 2. It is evident that, to raise fifteen pounds to a height of 142 feet, is the same thing as to raise 142 times fifteen pounds, that is, 2130 pounds, or nearly a ton weight, to a height of 1 foot; and, hence, it may be stated, in round numbers, that *the mechanical force produced by the evaporation of a cubic inch of water is sufficient to raise about a ton weight to the height of one foot.* 3. Let us now suppose the piston to be loaded with another weight of fifteen pounds, so as to be acted upon by a pressure equal to that of two atmospheres. The results would be, that a temperature of about 250° would be required to convert the water into steam, and that the piston would be raised to 72 feet, or little more than half its former height. In this case, the mechanical force would be sufficient to raise double the former weight to half the former height. And it may be stated, generally, that the height to which the piston would be

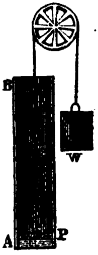

Fig. 4.

raised, would be diminished in a proportion somewhat less than that in which pressure on the piston is increased.

12. *Economical Applications of Heat.*—The following cases, in which the application of heat, evolved by the economy of fuel, is made subservient to practical purposes, are copied from the last edition of Dr. Lardner's Treatise on the Steam Engine:—

(1.) A pint of water may be evaporated by two ounces of coals. In its evaporation it swells into two hundred and sixteen gallons of steam, with a mechanical force sufficient to raise a weight of thirty-seven tons a foot high. The steam thus produced has a pressure equal to that of common atmospheric air; and by allowing it to expand, by virtue of its elasticity, a further mechanical force may be obtained, at least equal in amount to the former. A pint of water, therefore, and two ounces of common coal, are thus rendered capable of doing as much work as is equivalent to seventy-four tons raised a foot high.

(2.) The circumstances under which the steam engine is worked on a railway are not favourable to the economy of fuel. Nevertheless a pound of coke burned in a locomotive engine will evaporate about five pints of water. In their evaporation they will exert a mechanical force sufficient to draw two tons' weight on the railway a distance of one mile in two minutes. Four horses working in a stage coach on a common road are necessary to draw the same weight the same distance in six minutes.

(3.) A train of coaches weighing about eighty tons, and transporting two hundred and forty passengers with their luggage, has been taken from Liverpool to Birmingham, and back from Birmingham to Liverpool, the trip each way taking about four hours and a quarter, stoppages included. The distance between these places by the railway is ninety-five miles. This double journey of one hundred and ninety miles is effected by the mechanical force produced in the combustion of a quarter of a ton of coke, the value of which is six shillings. To carry the same number of passengers daily between the same places by stage coaches on a common road, would require twenty coaches and an establishment of three thousand eight hundred horses, with which the journey in each direction would be performed in about twelve hours, stoppages included.

(4.) The circumference of the earth measures twenty-five thousand miles; and if it were begirt with an iron railway, such a train as above described, carrying two hundred and forty passengers, would be drawn round it by the combustion of about thirty tons of coke, and the circuit would be accomplished in five weeks.

(5.) In the drainage of the Cornish mines the economy of fuel is much attended to, and coals are there made to do more work than elsewhere. A bushel of coals usually raises forty thousand tons of water a foot high; but it has on some occasions raised sixty thousand tons the same height. Let us take its labour at fifty thousand tons raised one foot high. A horse worked in a fast stage-coach pulls against an average resistance of about a quarter of a hundred weight. Against this he is able to work at the usual speed through about sixteen miles daily: his work is therefore equivalent to one thousand tons raised one foot. A bushel of coals consequently, as used in Cornwall, performs as much labour as a day's work of fifty such horses.

(6.) The great pyramid of Egypt stands upon a base measuring seven hundred feet each way, and is five hundred feet high, its weight being twelve thousand seven hundred and sixty millions of pounds. Herodotus states, that in constructing it, one hundred thousand men were constantly employed for twenty years. The materials of this pyramid would be raised from the ground to their present position by the combustion of about four hundred and eighty tons of coals.

(7.) The Menai Bridge consists of about two thousand tons of iron, and its height above the level of the water is one hundred and twenty feet. Its mass might be lifted from the level of the water to its present position by the combustion of four bushels of coal.

RECAPITULATION.

1. How is the *bulk* of bodies affected by Heat? State the comparative *expansibility* of bodies in the three states of solid, liquid, and gaseous. What is the *thermometer?* On what principle is it constructed? How is Fahrenheit's thermometer graduated? What modes of graduation are adopted in the Centigrade, and in Reaumur's, thermometer? How may the three modes of graduation be mutually referred to each other?—2. State the three mechanical forces in which Steam Power originates. On what two circumstances do the changes of *form*, exhibited by matter, depend?—3. What phenomenon takes place during the melting of a mass of ice? What is the meaning of *latent* heat? What is the latent heat of water? How may it be proved? What is meant by *sensible* heat? How may the *latent* heat of water be rendered *sensible?*—4. Explain the process of *ebullition*. What is the *latent* heat of steam? How may the *latent* heat of steam be rendered *sensible?*—5. What are the ingredients of *sea water?* How does the use of sea water act prejudicially in the steam engine? How is the boiling point affected in sea water?—6. What is the amount of the pressure of the atmosphere? How does this pressure affect the boiling point of liquids? State some of the variations which occur between the atmospheric pressure and the boiling point of water. What is meant by two or more atmospheres? How may the effect of atmospheric pressure upon the boiling point of water be proved? Explain the experiment of the flask, described in the eighth page.—7. State the general

law of the *directions* in which the pressure of fluids is exerted. What relation does the *elastic* property of a fluid bear to the capacity of the vessel which contains it? Explain the structure, and the principle, of the *barometer*. How may the elastic force of a portion of atmospheric air be estimated by means of this instrument? By what agency is the elasticity of a fluid increased?—8. What is Steam? What quantity of water is required to produce a cubic foot of steam? What relation subsists between the *elastic force of steam* and the *pressure of the atmosphere?* What is meant by *high-pressure steam?* What are the comparative forces of steam, as generated from *fresh*, and from *salt*, water, at the same temperature?—9. What is meant by *condensation* of steam? What are the means employed for condensing steam? Explain the phenomena which take place in the condensation of steam.—10. In condensing a cubic foot of steam, what amount of *vacuum* is produced? Illustrate the production of a vacuum by experiment.—11. Apply the foregoing principles to the action of a piston within a tube. By what force does the piston *ascend?* By what force does it *descend?* What amount of mechanical force may be produced by the evaporation of a cubic inch of water?—12. Give some striking instances of the economical applications of heat.

CHAPTER II.

EARLY APPLICATIONS OF STEAM POWER.

13. *General Remarks.*—In the preceding chapter have been explained the natural phenomena on which the sources of steam power depend. But these forces cannot be made *immediately* applicable to the purposes of locomotion: an *upward* force may be required, but water falls *downward;* a *circular* motion may be wanted, but the impelling power of wind is *rectilinear;* a *particular* direction may be necessary in which the pressure of steam is to be exerted, but steam presses with equal force in *every* direction; in a word, the motion of the impelling power may be of one kind, and that required at the working point, of another and very different kind. The forces, therefore, which actually exist in nature, or are called into existence by art, must be determined to the purposes required, by means of *machinery*, the great object of which is change, or modification, of motion. A vertical motion, for instance, being produced by the fall of a stream of water, a circular motion is readily procured by the introduction of a wheel furnished with cavities around its circumference; the paddle-wheel of a steam-boat furnishes an example of a continued rectilinear, produced by a continued circular, motion; an undershot water-wheel affords a continued circular, produced by a continued rectilinear. The *principle* by which the steam engine becomes a moving power, is exceedingly simple; the complexity arises from the various kinds of machinery by which the force is applied to the required purpose. The history of the steam engine presents a series of the most brilliant applications of ma-

chinery which have ever been witnessed; and it is the object of this chapter, to trace the rise and progress of the invention, and to conduct the reader, by easy steps, from its simple to its complex state; from the first production of the moving power, through the subsidiary details of mechanism which have been successively introduced.

14. *Hero's Machine.*—The generation of steam from water by the application of heat, and the mechanical force produced by this means, appear to have been understood at a very remote period; but their application to machinery devoted to the purposes of locomotion, is a discovery of recent date. The ingenious contrivances of early discoverers were devoted to objects of minor importance, as those of raising water, of propelling smoke upwards, &c. About 120 years before the present era, an elegant machine was constructed by Hero, of Alexandria, in which a rotatory motion was produced by means of steam. A hollow globe placed on pivots, was furnished with a number of horizontal tubes radiating from it like the spokes of a wheel, and closed at their extremities, with the exception of a small orifice near the end, and on the side, of each tube. The globe being supplied with steam, this fluid rushes through the orifices with a force equal to the excess of its elasticity over that of the atmosphere. The recoil produced by this difference of pressure, repels the tubes in the opposite direction, and a rotatory motion is produced, which may be communicated to machinery connected with the globe.

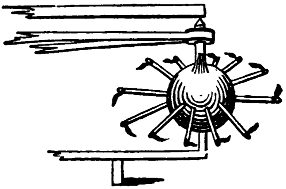

Fig. 5.

15. *Garay; De Caus; Branca.*—A long interval ensued, during which there appears to have been no discovery in the application of steam power to locomotion. 1. In 1543, Blasco de Garay, a Spanish sea captain, invented a machine by which a vessel could be propelled without oars or sails.

The experiment was made in the port of Barcelona, and appears to have been successful. But the nature of the apparatus, with the exception of a boiler having been employed, and wheels attached to the sides of the vessel, was concealed, and the experiment was not repeated. 2. In the early part of the next century, De Caus, a Frenchman, published a Treatise on Moving Powers and Machinery, which contained some indistinct views of the processes of evaporation and condensation, but conveyed no intelligible ideas of the elastic force of steam. He ascribed the mechanical force, occasioned by the conversion of water into steam, to the action of heat upon the *air* which is mixed with the water. He discovered that "water will mount by the help of fire, higher than its level;" but this process is described by him as depending on physical causes altogether unconnected with the properties of steam; the term *steam*, in fact, is not mentioned in his description of his machine. 3. In 1629, Giovanni Branca, an Italian, contrived a machine which was employed for the various purposes of raising water, of sawing timber, of pounding materials, &c. His machine consisted of a wheel furnished with flat vanes around its circumference, like the boards of a paddle-wheel. Upon these vanes, steam was propelled from a close vessel. A rotatory motion was produced, and communicated to appropriate machinery. The results, however, of these and other discoveries made about this period, have never been rendered applicable to the purposes for which the modern steam engine is adapted.

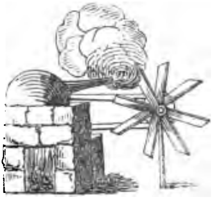

Fig. 6.

16. *Marquis of Worcester.*—In 1663, the Marquis of Worcester published a work, in which he described a method of raising water to great heights by the pressure of steam. He found that the force of steam was sufficient to burst a cannon; and, under the head of a *Fire Water Work*, he states:—"One vessel of water rarefied by fire, driveth up

forty of cold water; and a man that tends the work is but to turn two cocks, that, one vessel of water being consumed, another begins to force and re-fill with cold water, and so successively, the fire being tended and kept constant; which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."* The nature of the machinery employed for this purpose is of less consequence to us than the fact, that an important step was here gained in the progress of invention, as, whatever apparatus was employed, *the steam was generated in one vessel, and applied to mechanical purposes in another*, according to the method at present adopted in steam engines. The effect produced was equivalent to raising 20 cubic feet of water one foot high, by means of one pound of coals, or about the 2000th part of the effect of a good steam engine. It is obvious that there was much loss of effect by the considerable amount of condensation produced by the contact of the steam with cold water. But the Marquis appears to have been unacquainted with the effect of condensation, and his plan of operation must consequently have been very simple.

17. *Sir Samuel Morland.*—In 1675, Sir Samuel Morland obtained a patent for a powerful machine, by which he was enabled to raise water from the Thames to the top of Windsor Castle, and even sixty feet higher, in a continual stream, at the rate of sixty barrels per hour. In 1683, he published a work on "The Principles of the New Force of Fire," which contains some calculations of the size of cylinders adapted for raising, by steam, a certain quantity of water, to a given height, in a minute. This work contains also an estimate of the amount of expansion of a quantity of water into vapour, which is remarkable for its approximation to the truth at this period. The machinery employed by Morland is not known. His researches appear to have had little influence on the progress of the practical application of steam, as it is employed in the present day.

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* A Century of the Names and Scantlings of Inventions, *Art.* 68.

18. *Denis Papin.*—In 1695, Denis Papin, a Frenchman, suggested the idea of raising a piston within a cylinder by steam, and forming a partial vacuum beneath the piston by condensing the vapour, by which means the atmospheric pressure might be brought to aid the effect of his apparatus. This contrivance for producing a moving power may be fully understood, by referring to fig. 3, p. 13, and the description there given. The atmospheric pressure being equivalent to a weight of fifteen pounds on the square inch, if the piston be supposed to have a diameter of only one square foot, a power is here obtained of equal amount to a pressure of 1710 pounds. "The real authors of the atmospheric engine," observes Tredgold, "were very likely indebted to this suggestion; but neither Papin himself, nor his rival Savery, discovered how to turn this suggestion to advantage." Papin was, in fact, ignorant of the means of procuring an effective vacuum; he proposed to produce it by means of gunpowder, and afterwards by common air-pumps worked by a water-wheel; the fire was alternately applied to, and removed from, the cylinder; but the vacuum was always insufficient. Papin, however, produced a more perfect engine, after he had become acquainted with Savery's machine, which, in the order of discovery, must be next noticed.

19. *Savery's Steam Engine.*—Thirty years after Lord Worcester's death, Captain Thomas Savery constructed an engine, in which the force of steam is employed as a moving power for raising water. He appears to have discovered the principle of condensation by chance. Having drunk a flask of Florence wine, and thrown the flask on the fire, he called for a basin of water to wash his hands. He observed that a small quantity of wine remaining in the flask began to boil, and that steam issued from the flask. He then seized the vessel, and plunging its mouth under the surface of the water in the basin, found that the liquid rushed into the flask. This experiment suggested to him the possibility of producing *a vacuum by the condensation of steam*, and bringing the atmospheric pressure to bear upon the vacuum thus pro-

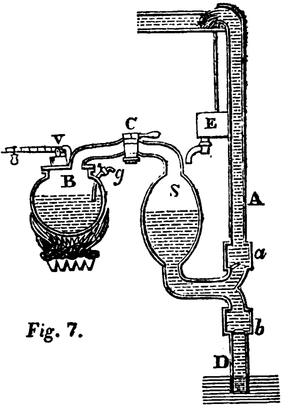


Fig. 7.

duced. The adjoining figure, copied from Tredgold's work on the Steam Engine, illustrates the apparatus employed by Savery. It consists of a furnace and a boiler B; from the latter, two pipes, furnished with stopcocks C, proceed to two steam vessels S, only one of which is shown in the figure, the other being immediately behind it. Into the bottom of each of these steam vessels is inserted a branching pipe, connected with a descending main pipe D, and an ascending main pipe A; each branching pipe is furnished with valves *a*, *b*, which open upwards, and prevent, by their action, the return of any water which may have been forced up through them. One of the steam vessels being filled with steam, condensation is produced by projecting cold water, from a small cistern E, against the vessel; and into the partial vacuum, thus made, the water is forced up, by the pressure of the atmosphere, through the descending main pipe, from a depth of about twenty feet. The steam being then introduced again into the steam vessels, the valve *b* is closed, and the descent of the water prevented; while the steam from the boiler pressing on the water in the steam vessel, causes it to raise the valve *a*, and ascend to a height proportional to the excess of the elastic force of the steam above the pressure of the air. In this engine, accordingly, water is raised, partly by means of a vacuum produced by the condensation of steam, and partly, by the elastic force of steam; the same steam which is subservient to the *forcing* effect being rendered, by its subsequent condensation, subservient to the re-production of the required *vacuum*. This engine was afterwards much simplified, one steam vessel only being employed. The risk of bursting the boiler was obviated by the use of the steel-yard safety valve V. The stopcocks C, by which communication is opened with, or shut off from, the boiler, were managed by the hand, the one being opened when the other is closed. The boiler was supplied with hot water from a smaller boiler, in order to prevent loss of time in refilling it with cold water. The quantity of water in the boiler was ascertained by means of the gauge cock *g;* if steam issues from this cock, when opened, there is too little water in the boiler. Savery's engine was successful in cases in which it was required to raise water to a height of only forty feet, but was inapplicable to the important object of draining mines, owing to the vast quantity of steam wasted by condensation in a cold vessel, and by means of cold fluid, and the danger of employing steam of sufficient power to raise water to the height required.

20. *Papin's Engine.*—Having become acquainted with Savery's engine, Papin published a work entitled " A New Method of raising Water by Fire," in which his own engine is described in its most improved state. It consists of a boiler *a*, having a tube *b*, by which it is supplied with water, and which is closed by a lever valve regulated by a weight *c*. The boiler is connected, by a steam pipe furnished with a stopcock *d*, with a cylinder *f*. The cylinder is closed at the top, where it is provided with a

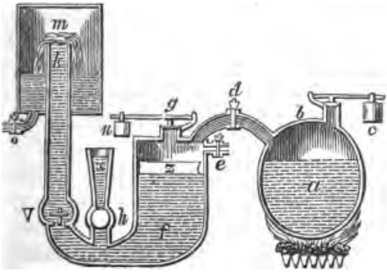


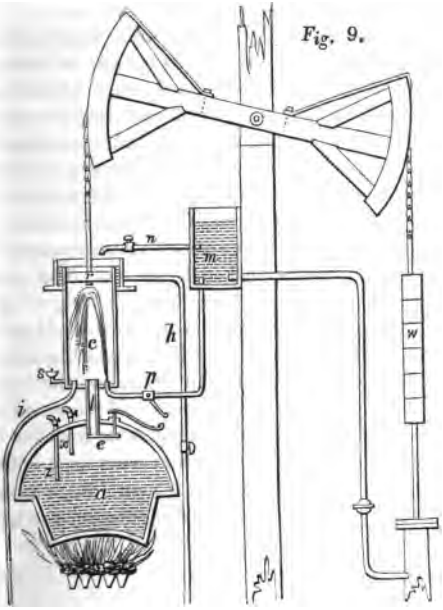
Fig. 8.

lever valve *g*, regulated by the weight *u*; the cylinder terminates below in a curved tube, which ascends into a reservoir *m*; the cylinder contains a floating piston *z*. Into the curved tube is inserted a funnel *x*, communicating with a reservoir of water, and having a valve at *h*. The operation of this machinery is as follows:—The cylinder *f* is filled with cold water by the funnel *x*; the boiler *a* contains steam of strong pressure. On opening the cock *d*, the steam passes into the cylinder *k*, and pressing upon the floating piston, forces the water into the reservoir *m*; its return is prevented by a valve V at the lower part of the cylinder. The stopcock *d* being then closed, and the cock *e* opened to allow the escape of the steam, the cylinder is again filled by the funnel *x*, and the above process repeated. The water which has been forced into the reservoir *m*, is directed to any useful purpose by the pipe *o*. In this engine, the principle of forming a vacuum and bringing the atmospheric pressure into operation, is abandoned; the moving power being produced simply by the expansive force of steam. Papin considered this engine to be more effective than that which he had previously proposed. "We now raise water," he says, "by the force of fire, in a more advantageous manner than that which I had published some years before; for, besides the suction, we now also use the pressure which the water exerts upon other bodies in dilating itself by heat; instead of which I before employed the suction only, the effects of which are more limited."

21. *Newcomen's Atmospheric Engine.*—The drainage of deep mines was a matter of great importance, and the failure of Savery's and Papin's engines in this respect paved the way to further experiment. In 1705, Thomas Newcomen, a smith of Dartmouth, obtained letters patent for the construction of a new kind of steam engine, in which he availed himself of the atmospheric pressure in a different way from that adopted by Savery. The novelty of this plan consists in *the admission of steam beneath an air-tight piston, and the condensation of the steam by the injection of cold water*

into the interior of the cylinder. The use of a cylinder and piston may be easily explained. In order that the pressure of steam may be rendered available in machinery, the steam must be confined within a cavity which is air-tight, and so constructed that its dimensions, or capacity, may be altered with altering its tightness. When the steam enters such a vessel, it enlarges its actual cavity, by causing some moveable part to recede before it, and from this moveable part motion is communicated to machinery. A hollow cylinder having a moveable piston accurately fitted to its bore, constitutes a vessel of this kind; the piston, thus employed, has an alternate or reciprocating vertical motion, which may be converted into a circular motion by appropriate machinery. The engine employed by Newcomen, in its most improved state, was as follows:—Over a boiler *a* is

Fig. 9.



fixed a cylinder *c*, containing a piston *r*, the rod of which is connected with one of the arched extremities of a lever beam working on a pivot; to the other extremity of the beam is attached a chain connected with the pump-rod. Such is the simple outline of the Atmospheric Engine. Its mode of operation is as follows:—Steam is admitted from the boiler into the cylinder, through the tube *l*, by means of a *regulating cock e*, which is worked by a handle outside the boiler; the pressure of the atmosphere above the piston being thus balanced by the force of the steam beneath it, the extremity of the lever beam to which the piston is attached is elevated by proportionate weights *w* attached to the pump-rod, and the piston is drawn to the top of the cylinder, the other extremity of the beam being depressed. In order to effect the *descent* of the piston, the steam in the cylinder must now be condensed. The regulating cock *e* is accordingly closed, and the further admission of steam prevented; another cock, called the *condensing cock p*, is now opened, and a jet of cold water is admitted through a tube from the cistern *m*, which is placed at a sufficient height to ensure a forcible injection; the steam in the cylinder is instantly condensed, a vacuum is formed, and the pressure of the atmosphere forces the piston to the bottom of the cylinder, while the pump-rod on the other end of the beam is raised. Such is the general operation of Newcomen's Atmospheric Engine, which is merely a pump worked by steam. The subsidiary details of its operation are now to be explained.

(1.) The *quantity of water in the boiler* is regulated by the two *gauge cocks*, *x*, *z*, one of which *x* has its aperture a little above the required height of water, the other *z* a little below it. On opening the cocks, if the water is at its proper height in the boiler, steam will issue from the cock *x*, and water from the cock *z;* if *steam* issue from both, there is too little water in the boiler; if *water* issue from both, there is too much. This mode of regulating the height of water in the boiler was the invention of Savery, and is employed in the present day.

(2.) A contrivance is added for the purpose of *getting rid of the air contained in the cylinder* before the engine is in full play, and thus preventing the engine from being *air-logged.* Near the bottom of the cylinder is inserted a small tube, opening into the atmosphere, where it is furnished with a valve, which opens upwards, and is inserted into a sort of cup *s*, containing water. The heated air and steam in the cylinder, having sufficient elastic force to overcome the atmospheric pressure, open this valve and escape with a hissing noise. This operation is called *blowing the engine*, before it starts; and the valve, from the peculiar noise attending the process, is called the *blowing* or *snifting valve.*

(3.) The next object is *to get rid of the injection water* and the condensed steam; for, however small the quantity might be after a few condensations, it is evident that it would quickly accumulate in the cylinder, and entirely check the movement of the piston. To carry this off, a pipe *i*, called the *eduction pipe*, is inserted into the bottom of the cylinder, and conveyed downwards into a reservoir, called the *hot-water cistern.* This pipe, as represented in the figure, must be made to descend thirty feet below the cylinder; for otherwise, being connected with a vacuum produced by the alternate motion of the piston, the atmospheric pressure would force the water to ascend from the cistern into the cylinder, instead of the water descending from the cylinder into the cistern. This difficulty is, however, easily removed by placing a valve opening downwards, called the *eduction valve*, at the outlet of the pipe *i* in the bottom of the cylinder; the cistern, in this case, may be situated close to the cylinder.

(4.) The *cistern m* is supplied with cold water, by a pump which branches from the main pump, and is worked by the engine. The pipe *n* admits a stream of water upon the piston, in order, by interposing a denser substance than the air, to render the piston more air-tight. The pipe *h* conducts the water, which becomes heated, from the top of the cylinder into the hot cistern below. The idea of condensing the steam by injecting water into the cylinder, appears to have been suggested by accident. At first, Newcomen enclosed his cylinder within another cylinder, and condensed the steam by filling the space between them with cold water by the pipe *n*. On the first trials of this engine, the managers were surprised to see it, without its regular supply of condensing water, "go several strokes, and very quick together; when, after a search, they found a hole in the piston, which let the *cold water in to condense the steam in the inside* of the cylinder, whereas before they had always done it on the outside." The external cylinder was, accordingly, abandoned, and water was henceforth injected from below, as already described. So true is it, that "the wished-for improvement is unmade, oftener because the means are overlooked, than because they are hidden from us."

22. *Potter and Beighton.*—It is evident from the preceding description, that the effectual working of Newcomen's Engine depended upon the alternate opening and closing of two valves, viz. the regulating, and the condensing valve; and that these manipulations depended on the unremitting attention and precision of the person who managed the machine. It was his duty to open the regulating valve, and to watch the ascent of the piston; then to close that valve, and open the condensing valve; and these alternate movements were to be repeated fourteen times every minute. The infliction of this task induced a boy, called Humphrey Potter, to contrive a means by which the engine should work its own valves, while he was at play. He attached strings to the levers of the valves, and fastened these strings to the beam in such a manner, that as the beam ascended and descended, not only were the valves opened and closed with regularity, but the speed of the engine was actually doubled. This contrivance was afterwards improved, and a more permanent mechanism added by Mr. Beighton. In room of the catches and strings hitherto employed, he attached to the working beam a straight rod, called a *plug frame*, which by means of

pins or pegs fixed into it, opened or closed the valves with certainty, as the beam ascended or descended. An important step was thus gained towards the completion of a self-regulating machine: to supply the fire with fuel, and the boiler with water, was all the attendance now required. The Atmospheric Steam Engine, as improved by Beighton, in 1712, was very generally adopted in coal works and copper mines.

23. *Leupold's High-Pressure Lever Engine.*—A few years afterwards, an ingenious German, named Leupold, introduced the first experiment of a *high-pressure engine* worked by a cylinder and piston, and adapted to his machinery a contrivance, first indicated by Papin, of a *four-way cock.* His plan may be illustrated by the adjoined figure. Over a boiler B are placed two cylinders C C, each being provided with an air-tight piston *p, p;* each of the piston-rods is attached to one end of a lever working on a pivot, the other end of the lever having a pump-rod fixed to it. A four-way cock S is fixed between the boiler and the cylinders, so as alternately to admit steam into one cylinder, and permit its escape from the other. Steam of high temperature is introduced from the boiler into one of the cylinders, the piston is raised to the top of the cylinder, the pump-rod at the other end of the lever is pressed downwards, and the plunger or piston attached to it being solid, the water is raised to the required height in a force-pipe. The *four-way cock* is then turned round, and the steam escapes from this cylinder into the atmosphere, while steam from the boiler is admitted into the other cylinder; the direction of the two channels from the boiler to the cylinders, is, in fact, exactly

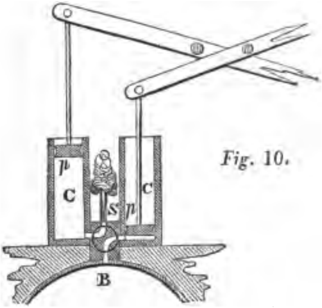


Fig. 10.

reversed, and thus, by the alternate action of the steam in the two cylinders, a continued stream of water is raised.

24. *Hulls' Steam-Boat.*—In 1737, the first application of steam to navigation was suggested by Jonathan Hulls, in a pamphlet entitled, "A description and draught of a new-invented machine for carrying vessels or ships out of or into any harbour, port, or river, against wind or tide, or in a calm." His plan of adapting a vertical to a rotatory motion, is shown in the adjoined figure. The machinery was fixed in a tow-boat. It consists of three wheels, *a b c*, fixed on one axis, and two wheels, *d e*, with *ratchets*[*] loose on another axis, so that this axis can only move in the forward direction. To the latter axis are attached the fans or paddles which serve to propel the vessel. The wheels are furnished with ropes, *f g h;* the rope on the wheel *b* is attached to the piston P of the engine. As the piston descends, the wheels *a b c* move forward, and cause the wheels *d e* to move; but owing to the different situation of the ropes *g h*, the wheel *e* moves forward, while the wheel *d* moves backward. The latter wheel, in moving

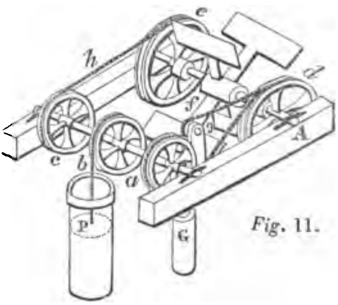


Fig. 11.

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[*] The object of *ratchets* is to prevent motion in one direction, while they permit it in another. The adjoined figure represents a ratchet or detent wheel. It will be observed that the teeth are cut with their faces inclining in one direction, and a small lever or catch is so placed, as to enter the indentations and stop the wheel if it turns backward, but slides over the teeth without obstructing them, if it moves forward. Ratchet wheels are generally employed to prevent a weight raised by a machine from descending, and to obviate other retrograde movements.

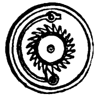

Fig. 12.

backward, raises a weight G, which is attached to it, by the rope *f*, acting over a pulley. During the ascent of the piston, the weight G pulls the wheel *d* forwards; hence the axis A, bearing the paddles, is constantly moving round in the same direction and by an equable force. "This is certainly," as Tredgold observes, "a beautiful contrivance for rendering so irregular a first mover equable; and considering the object it was intended for, it is not a complex arrangement; for besides equalizing the power, it gives a means of increasing or diminishing the velocity in the ratios of the diameters of the wheels."

25. *Payne and Howard.*—A new method of generating steam was attempted by John Payne. His apparatus consisted of two vessels; one of these, shaped like a balloon, and called the expanding vessel, was kept at a dark-red heat by the flue of a furnace; the other was inserted within it, and resembled a kind of drum, having a series of pipes radiating from its circumference. The latter vessel, called the *disperser*, was made to revolve on a pivot, somewhat in the way represented at page 19, and was supplied with water by a vertical pipe, which passed through the exterior vessel. When water was introduced by the vertical pipe into the disperser, it was thrown by the revolutions of this vessel on that portion of the exterior vessel which was exposed to the heat of the furnace, and a rapid production of steam was thus occasioned. Payne says, that in the course of an hour he evaporated, by this method, forty gallons of water, which supplied a twenty-four inch cylinder; and in experiments made at Wednesbury and Newcastle-upon-Tyne, he rarefied ninety gallons of water in an hour, by means of 112 pounds of pit-coal, being, he observes, about one-third only of the fuel required for the same purpose in common boilers. The principle of producing steam from the least possible quantity of water on a small surface, has been recently adopted with success by Mr. Howard, whose apparatus will be noticed hereafter. In his engine, other liquids, as alcohol, may be substituted for water.

26. *Smeaton.*—The Atmospheric Engine, having received slight improvements in its structure from various contributors, was brought to its most finished state in the hands of Smeaton, in 1772. This industrious engineer first designed a portable atmospheric engine; the fire-place was of a spherical form, and enclosed within the boiler; and in the room of the lever beam, a wheel of 6·2 feet in diameter, furnished with a chain, communicated the motion from the piston to the pump-rod. His attention was also directed to the economizing of fuel, the expenditure of which he appears to have reduced to about one-third. His next endeavour was to determine the load upon the piston; he appears to have fixed the amount at nearly eight pounds on the square inch of the piston, though he observes that any load may be employed, if the several parts of the engine be proportionably constructed. "The labours of Smeaton," observes Tredgold, "show the imperfect state of mechanical science, as applied to practice, in a remarkable degree. Yet if it were his labours on the steam engine alone on which his fame rested, there would be sufficient to command our esteem and respect; its further improvements, its close cylinder, its double action, undoubtedly owed much of their perfection to the use of the modes of construction applied by Smeaton to the air-pump."

RECAPITULATION.

13. What is the general object of *machinery* in the construction of engines? Give an illustration of a *change of motion* produced by machinery.—14. Explain the construction, and principle, of Hero's machine.—15. Explain the machine of Branca.—16. What new principle was introduced by the Marquis of Worcester?—18. Explain the contrivance of Papin for the production of a moving power.

What was the principal defect in his early experiments?—19. What new principle was introduced by Savery? By what two powers was his engine made available to the purpose of raising water? In what respect was his engine defective?—20. What principle was adopted in the engine of Papin?—21. Explain the important change introduced in the *Atmospheric Engine* of Newcomen. Explain, generally, the use of a cylinder and piston in steam apparatus. What is meant by *gauge cocks*, and how are they employed? What is meant by *blowing the engine?* By what circumstance was Newcomen led to adopt the principle of injecting water within the cylinder?—22. What improvement was introduced by Potter? and by Beighton?—23. What was the principal feature in Leupold's Engine? Explain the action of the *four-way cock.*—24. Explain the mechanism and action of Hulls' Steam-boat.

CHAPTER III.

SINGLE ACTING ENGINE OF WATT.

27. *Era of Watt.*—The *Atmospheric Engine*, when brought to its most improved state by Smeaton, was still a more expensive power than that of horses, a considerable quantity of fuel and steam being consumed by it for useless purposes. To remedy these defects, and to introduce a new era in the history of the *Steam Engine* and Machinery, were reserved for the industry and talent of JAMES WATT. This extraordinary man was born at Greenock, in 1736. His attention was first directed to the subject of steam power in the year 1759. About two years afterwards, he constructed a model of a steam engine by adapting to the upper part of a Papin's digester (page 10), a syringe containing a solid piston; steam was admitted into the syringe by means of a stopcock, and the piston was raised; the stopcock was then closed, the steam permitted to escape by another cock inserted into the bottom of the syringe, and the piston descended. The practicability of a *high-pressure engine* was here proved; the principle was, however, abandoned, owing to the danger of bursting the boiler, the difficulty of making the joints tight, and the loss of a great part of the power of the steam from the non-production of a vacuum. In 1763, Watt had occasion to repair a model of Newcomen's engine belonging to the University of Glasgow; he observed the great waste of steam employed for the mere purpose of raising the temperature of the cylinder to a requi-

site height; he was surprised at the great quantity of injection water which was necessary, not only to condense the steam, but to reduce the temperature of the whole cylinder; he found that this quantity of water, becoming heated by contact with the hot cylinder, produced a steam within the cylinder which, to a certain extent, resisted the pressure of the atmosphere upon the piston. These circumstances led Watt to apply the powers of his mind to the construction of an engine upon a plan which had not hitherto been suggested.

28. *Separate Condensation.*—Watt perceived that, in order to make the best use of steam, the cylinder should be maintained always at the same temperature as the steam which entered it; and that the condensed steam and injection water should be cooled down to 100°, or lower, if possible. In following out these views, it occurred to him, in 1765, that *if a communication were opened between a cylinder containing steam, and another vessel which was exhausted of air and other fluids, the steam, as an elastic fluid, would immediately rush into the empty vessel, and continue to do so until it had established an equilibrium.* This was the earliest idea of condensation in a vessel separate from the cylinder. In 1769, Watt obtained a patent for his "Methods of lessening the Consumption of Steam, and consequently of Fuel, in Fire Engines;" of which the following is the specification:—

"First; That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it; first by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam, or other heated bodies; and thirdly, by suffering neither water, nor any other substance colder than the steam, to enter or touch it during that time.

"Secondly; In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam vessels or cylinders, although occasionally communicating with them. These vessels I call *condensers;* and whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water or other cold bodies.

"Thirdly; Whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam vessels or condensers, by means of pumps, wrought by the engines themselves or otherwise.

"Fourthly; I intend, in many cases, to employ the expansive force (pressure) of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire engines. In cases where cold water cannot be had in plenty, the engines may be wrought by the force of steam only, by discharging the steam into the open air after it has done its office.

"Lastly; Instead of using water to render the piston or other parts of the engine air or steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state.

"Be it remembered, that the said James Watt doth not intend that any thing in the fourth article shall be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

29. *Experiment of separate Condensation.*—No sooner had the idea of *separate condensation* occurred to Watt, than all the subsidiary improvements followed in quick succession. To place an air-tight cover over the cylinder, with a hole and air-tight box for the piston to slide through, and to admit the pressure of steam, instead of that of the atmosphere, to act upon the piston; to prevent the cylinder from cooling, by enclosing it within another cylinder containing

steam; to render the piston air-tight, not by a stratum of water placed over it, which is obviously inapplicable in the present case, but by means of lubricating substances; to remove both the air and the water, accumulated by injection and condensation of steam, by means of a pump: these improvements followed like corollaries in his mind, so that in the course of one or two days, the invention was put to the test of experiment. The adjoined figure represents one of the earliest models of the apparatus. A brass cylinder A is closed above and below with tin plate, and furnished with a pipe G H, for the purpose of conveying steam from the boiler B to both ends of the cylinder, and another pipe F to convey steam from the cylinder to an empty vessel, called the condenser C, into which an injection of cold water is admitted. The condenser communicates below with a tube and piston, which served for an air and water pump; the condenser and the pump were placed in a cistern of cold water. The cylinder is represented in the figure as inverted. The stem of the piston is perforated longitudinally, and a valve fixed to its lower end, to permit the escape of the water produced by the condensed steam, on first filling the cylinder. The operation of this machinery is as follows. Steam is admitted from the boiler into the cylinder and condenser, until all the air is expelled; this period is indicated by the steam issuing from the valve at the bottom of the piston-rod. The steam cocks H and G are then closed, and the piston of the air-pump drawn up; a vacuum is thus produced in the condenser, and the steam issues into it from the cylinder and is condensed. The piston of the cylinder immediately rises and lifts a weight of about eighteen pounds, which is attached

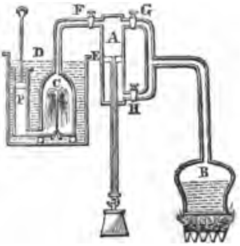

Fig. 13.

to the lower end of the piston-rod. The exhaustion cock F is then closed, and the steam cocks opened ; steam is again admitted into the cylinder, the weight carries down the piston, and the operation is repeated. The working of the model having succeeded, the cylinder was placed upward and furnished with a lever beam, as was usual in working engines.

30. *Single Acting Steam Engine.*—In the year 1775, a patent was obtained by Watt, for an engine which has been called his *Single Acting Steam Engine.* It was at first employed for raising water and draining mines, by means of pumps ; the motion required was, therefore, merely an upward force for raising the piston of a pump. This engine, in 1788, had attained the form presented in the opposite engraving. The apparatus here exhibited is enclosed within a building, the front of which is removed in order to show the works ; a vertical section is made of the several vessels composing the engine, that the construction and operation of each may be understood. On the left of the figure, and on the outside of the building, is the boiler, enclosed in a case of brickwork ; on the right of the figure, and also outside the building, are the pumps by which the water is raised. S is a steam pipe, by which steam is supplied from the boiler to the cylinder C. The cylinder is closed at the top by a lid, through which the piston-rod moves up and down in a steam-tight collar, called a *stuffing-box*, B ; the upper part of the piston-rod is attached to the arched extremity G of a lever beam, which moves on a pivot, as in the atmospheric engine. The mechanism, by which the cylinder is alternately supplied with, and exhausted of, steam, consists in a tube and three valves, connected with the right side of the cylinder ; of these, G is called the *upper steam valve*, and is contained in the upper steam box A ; H is the *lower steam valve*, and is contained in the lower steam box A' ; I is the *exhaustion valve*, through which the steam passes to the condenser below ; these three valves are opened and

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closed by means of handles, marked respectively G', H', I'. From the cylinder, the tube T' opens into the *condenser* D, which communicates by a valve M with the *air-pump*, N; the condenser and the air-pump are placed in a cistern of cold water, called the *cold well*, W; a jet of cold water is allowed to play into the condenser by means of a valve E. The piston of the air-pump is furnished with valves which open upward, to admit of the passage of air and water to the upper part of the pump, where they escape into the cistern by the valve K, which prevents their return; the piston of the air-pump is worked by a rod Q, connected with the lever beam.

31. *Operation of the Single Action Steam Engine.*—The above description of this engine will enable us readily to understand its mode of operation.

(1.) The first process consists in what is called *blowing through;* that is, clearing the cylinder, condenser, and pipes, from atmospheric air, and filling them with pure steam, preparatory to working the engine. For this purpose, let the three valves G, H, and I, be opened, and steam admitted from the boiler through the pipe S; the steam will presently displace all the air contained in the cylinder, the tubes, and the condenser; the pressure exerted by the steam and heated air in the condenser will open the valve M, the valves in the piston of the air-pump will be opened upward, the steam and air will escape through the valve K into the cold cistern, and the several vessels will be filled with pure steam. The engine is now in a fit state for effective operation.

(2.) The piston P being at the top of the cylinder, and the injection valve E being opened, a jet of water plays into the condenser, forming a vacuum, into which the steam from the cylinder instantly rushes through the tube T' and is condensed, leaving a vacuum in the cylinder below the piston. The valves H and I being now closed, and steam admitted by the valve G to the upper surface of the piston, this is immediately pressed down with a force corresponding to the pressure of the steam and the perfection of the vacuum in the cylinder. This portion of the *first stroke** of the engine, elevates the pump-rod R on the other side of the building, and raises the water to the height required.

(3.) The upward motion of the piston is effected as follows. The upper steam valve G being closed, and the lower valve H opened, the steam is admitted below as well as above the piston, which, so far as the steam is concerned, is in a state of equilibrium, there being no force to resist its motion upward or downward, except its friction against the surface of the cylinder. In this passive state of the piston, the weight of the water on the piston of the pump, together with the weights attached to the piston-rod of the pump, draw down the corresponding side of the lever beam, and thus raise the piston in the cylinder on the other side.

(4.) To effect the *second stroke* of the piston, the valve H must be closed, the valves G and I opened, and the condensing valve V opened, in order to admit a jet of water into the condenser. The steam in the cylinder below the piston will immediately rush through the valve I into the vacuous condenser, and be converted into water, leaving a vacuum in the cylinder, into which the steam, admitted by the valve G, will immediately force down the piston; and thus by the alternate opening and closing of the valves, the engine performs its work.

(5.) It is well known that water contains a considerable quantity of *air*, which, being uncondensible, remains in the gaseous state after the steam has been condensed; unless this air were removed from the condenser, it would collect and impede the motion of the piston. The mode by which this air, together with the injected water, and the water produced by condensation of the steam, are removed from the condenser, is as follows. The piston of the air-pump is raised by the lever-beam to the top of its barrel, at the same time that the steam piston is raised to the top of the cylinder; hence, a vacuum is produced in the barrel of the air-pump, and the water and air pass into it from the condenser through the valve M. As the piston of the air-pump descends, it presses first upon the air, which opens the piston valves upwards and passes through to the upper part of the piston, then upon the water, which also passes through the valves; these valves are then closed by the weight of the air and water, and the piston, in its next ascent, carries them both upwards, where they are discharged through the valve K into the cistern B.

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* By a *stroke* of the piston is meant a double motion, viz., from the top of the cylinder to the bottom, and upward again. Its motion in one only of these directions, is called the *length* of the stroke. Hence, if the length of the stroke be five feet, the stroke itself is ten feet.

32. *Application of Watt's Principle.*—The application of the principle of separate condensation, as introduced by Watt, depended *first*, on keeping the cylinder as hot as the steam; and *secondly*, on keeping the condensing water as cool as will suffice to render the vacuum perfect. 1. It is evident that by the cooling of the cylinder from exposure to the atmosphere, the steam within it would be liable to a diminution of force. To prevent this loss of heat, Watt first proposed to surround the cylinder with a casing of wood, this substance being a slow conductor of heat. He afterwards enclosed the cylinder within another cylinder, called a *jacket*, and kept the space between the two cylinders constantly filled with steam. 2. It is evident that the condensing water, injected into the condenser, must be sufficiently cold, not only to condense all the steam which issues from the cylinder, but to reduce its own temperature, when mixed with the condensed steam, below the point at which it would produce vapour of sufficient pressure to impede the action of the piston in the cylinder. From experiments made by Watt on the pressure of steam at different temperatures, he found, that for the effective operation of the piston, the temperature of the water in the condenser must be reduced to 100°.

33. *Quantity of injection Water.*—The *quantity of water* required to condense a given quantity of steam, so as to pro-

duce a constant and effective vacuum in the condenser, may be readily calculated. The *latent* heat of steam being computed at 1000° (page 5), and its *sensible* heat being 212°, or that of boiling water, the total amount of the heat of steam is 1212°; and this amount is to be *reduced* by the injection water to 100°. Supposing the injection water to be at the ordinary temperature of 60°, it is necessary for this to be *raised* to 100°. Hence it follows, that the *steam* must be deprived of 1112°, and the *water* must receive 40° of heat. If the former of these numbers be divided by the latter, the result will be 27·8, or, in a round number, 28. If, therefore, the entire contents of the boiler be supposed to be converted into steam, the amount of injection water must be 28 times greater than that of the water in the boiler. To meet this demand, it is necessary that the *cistern*, in which the condenser is placed, should be supplied with a sufficient quantity of water at the ordinary temperature of 60°. This is effected by means of a pump, called the *cold pump*, L, which is worked by the lever-beam of the engine, as represented in the engraving; as the water is pumped in, it sinks to the bottom of the cistern from its greater weight, while the portions heated by contact with the condenser rise to the top and are carried off by a waste pipe; the contents of the cistern are thus maintained at a uniform temperature. The pipe O forms a communication between the hot cistern and the boiler, and is intended to supply the latter with water. It will be more particularly noticed hereafter.

34. *Mechanism of the Valves.*—The several kinds of valve employed in steam engines, will be described in a subsequent chapter. The valves used in the Single Acting Engine of Watt, are those termed *spindle*, or *button valves*, and sometimes *puppet clacks;* they are seen in the engraving at G, H, and I. Each of them is provided with a lever, which plays on a pivot attached to the frame-work of the engine; the levers are furnished with arms or handles, G', H', and I'. The valves are opened and shut by means of a rod or bar, called the *plug-tree*, attached to the rod of the air-pump.

This plug-tree is provided at proper distances with projections, called *tappets*, which strike the handles of the levers, as the beam ascends or descends, and thus open or close the valves at the proper periods.

RECAPITULATION.

27. What were the defects of the Atmospheric Engine?—28. Explain the principle of *separate condensation.* By what circumstances was Watt led to this important improvement?—29. By what agent is the piston operated on, in its descent as well as its ascent, in the Single Acting Engine of Watt? In what respect does this contrivance differ from that of Newcomen? What alteration was introduced in the steam cylinder by Watt? How was the cylinder maintained at a uniform temperature? How was the action of the piston-rod secured?—30. Explain, generally, the structure of the *Single Acting Steam Engine*, with particular reference to the *condenser*, and the *air-pump*.—31. What is meant by a *stroke* of the engine? Give a general idea of the operation of the Single Acting Engine.—32. At what temperature is the cylinder maintained in this engine? At what temperature should the condensing water be preserved?—33. What *quantity of injection water* is required to condense a given quantity of steam?—34. What kind of valve is employed in this engine? What is the *plug-tree*?

CHAPTER IV.

DOUBLE ACTING STEAM ENGINE OF WATT.

35. *Advantages of Watt's over Newcomen's Engine.*—The advantages of the *Single Acting Steam Engine* of Watt, over the *Atmospheric Engine* of Newcomen, may be briefly recapitulated. In the first place, the elastic force of steam is substituted for the atmospheric pressure, in carrying the piston to the bottom of the cylinder; the power of Watt's engine is, therefore, capable of increase or diminution, according to the pressure of the steam employed, whereas Newcomen's engine is subjected to a less varying degree of pressure, viz., that of the atmosphere. Secondly, in Newcomen's engine, there is considerable loss of effect by the cooling of the cylinder and piston, owing to exposure to the atmosphere; in Watt's engine, this defect is remedied by closing the cylinder at the top, and encasing it entirely in an outer cylinder of wood, or some material of low conducting power. Thirdly, in the Atmospheric Engine, the piston is rendered air-tight by means of water on its surface, and this contributes to cool the cylinder; in the Steam Engine, in which water would be obviously inadmissible, the same effect is produced by the application of melted tallow, oil, and other liquid matters, to the piston. Fourthly, in Newcomen's engine, the steam is condensed in the cylinder, by which means the cylinder itself becomes cooled, air and water accumulate within it, and the vacuum is rendered imperfect; in Watt's engine, the steam is condensed in a separate vessel, the contents of which are removed by means of an air-pump; a good vacuum is thus formed without

cooling the cylinder. In both these engines, however, there is one grand defect—*the motion produced by them is intermitting;* in the one case the pressure of steam, in the other the pressure of the atmosphere, is rendered available to only *one half of the stroke of the piston*, viz., the downward motion; the upward motion, or other half of the stroke, being effected by a counter weight attached to the further extremity of the beam. It is obvious that the upward motion can communicate no impulse to machinery, and that the engine in both cases is necessarily limited in its application to the raising of water; in other words, that it is a mere pump, worked by steam instead of by horses.

36. *Sun and Planet Wheels.*—In 1781, Watt obtained a patent for some new methods of applying the reciprocating motion of the steam engine to produce a continued rotative or circular motion round an axis or centre, and thereby to give motion to the wheels of mills and other machines. One of the earliest of these contrivances, was the machinery termed, from its characteristic action, the *sun and planet wheels*. It is illustrated in the adjoined figure, in which a large metallic wheel, called a *fly-wheel*, is represented, to which a rotative motion is to be given. Upon the centre or axis of this wheel, a small toothed wheel, called the *sun-wheel*, is firmly fixed, so that they both revolve together. The sun-wheel works in gear with another toothed wheel, called the *planet-wheel*, the latter being so fixed to a rod as to be incapable of revolving on its centre. The rod is connected with the extremity of the working beam of the engine. Supposing the *planet-wheel* to be placed vertically beneath the sun-wheel, and the extremity of the lever to which it is attached to be at its lowest point of depression, it is obvious that, as the beam ascends, the planet-wheel will be carried to the top of the sun-wheel, and that, with the descent of the beam, it will be carried again to the bottom, and thus perform *one revolution* at each stroke of

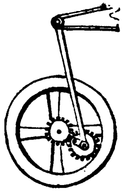
Fig. 14.

the piston. But, as the planet-wheel does not revolve on its axis, it follows that for each revolution made by this wheel, the *sun-wheel*, and consequently the fly-wheel, will have performed *two revolutions.* The reader, who may be unacquainted with the laws of mechanics, may verify this statement by a simple experiment. Let him place two coins on the table, the one above the other on the same plane, and having their images in the erect position; let him prevent one of the coins from revolving on its axis, by placing his finger on it, and gently rotate the other coin around the circumference of the fixed one; he will find that the image upon the revolving coin will present the erect position *twice* in completing *one* revolution around the fixed coin. The fixed coin represents the planet-wheel, and the revolving coin the sun-wheel. This contrivance was applied to many engines, and it possesses the advantage of communicating a double velocity to the fly-wheel; but the teeth of the wheels are soon injured by wear, and the machinery is liable to be broken by heavy strains. This method of producing the rotative motion, was soon superseded by that of the *crank*, which will presently be described.

37. *Principle of the Double Acting Engine.*—In considering the applicability of the steam engine to manufactures generally, it occurred to Watt, that if he could contrive to *admit steam alternately above and below the piston, and at the same time produce a vacuum alternately below and above the piston*, an impulse might be communicated by the ascent, as well as by the descent, of the piston, and a uniform *continuous action* be thus produced. It was desirable, also, to convert this reciprocating action into a circular one, by a more effective means than that of the sun and planet wheels. On this subject Watt observes:—"Having made my single reciprocating engines very regular in their movements, I considered how to produce *rotative motions* from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose, as the

application of the *crank*, in the manner of the common turning lathe; but as the rotative motion is produced in that machine by impulse given to the crank in the descent of the foot only, it requires to be continued in its ascent by the energy of the *wheel*, which acts as a *fly*. Being unwilling to load my engine with a fly-wheel heavy enough to continue the motion during the ascent of the piston (or with a fly-wheel heavy enough to equalise the motion, even if a counter-weight were employed to act during the ascent), I proposed to employ two engines, acting upon two cranks fixed on the same axis, at an angle of 120° to one another, and a weight placed upon the circumference of the fly-wheel at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and only a very light fly-wheel would be requisite." In following out this plan, some very important changes were introduced into the machinery of the steam engine: the principal of these are the double acting cylinder, the parallel motion, the crank, the fly-wheel, and the governor. Each of these will first be severally described; and their operation in the double acting engine be afterwards pointed out.

38. *Double Acting Cylinder.*—The first alteration to be noticed in the double acting engine is that of the cylinder. To ensure its *double action*, it is necessary to provide, at each end of the cylinder, a means of *admission* of steam from the boiler, and of *escape* for the steam to the condenser. For this purpose, a *steam box* is fixed to each end of the cylinder, communicating in the one case with the upper, in the other with the lower, surface of the piston. In fig. 15, B is the upper, and B' the lower, steam box. Each of these boxes is furnished with two valves. 1. In the *upper steam box*, the upper, or *steam valve*, S, admits steam from the boiler through a tube, the mouth of which is

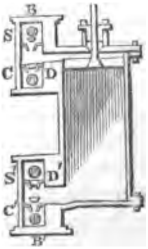

Fig. 15.

seen immediately above the valve; the lower, or *exhausting valve*, C, permits the escape of the steam from the cylinder to the condenser, through a tube opening immediately below the valve. In this figure, the piston is at the top of the cylinder; the exhausting valve is therefore represented as closed, and the steam valve as open, for the admission of steam, which rushes through the passage D to the top of the cylinder, in order to force the piston to the bottom. 2. In the *lower steam box*, a corresponding mechanism is observed, and its valves must be worked at the same moment as those of the upper box, but upon an exactly opposite principle. The cylinder is full of steam, and the piston at the top; the *steam valve* S' must therefore be closed, and the *exhausting valve* C' opened, in order that the steam may rush out at the passage D', and a vacuum be formed *beneath* the piston, to give effect to the steam which is now entering above it.

In figure 16, the piston is at the bottom of the cylinder. 1. In the *upper steam box*, the *steam valve* S is accordingly closed, and the *exhausting valve* C opened, to admit of the escape of the steam from above the cylinder through the passage D into the condenser, and thus to produce a vacuum *above* the piston. 2. In the *lower steam box*, the *exhausting valve* C' is closed, and the *steam valve* S' opened, in order that steam may rush in by the passage D', and force the piston to the top of the cylinder. From the preceding description, it is evident, that the alternate motions of the piston depend on the opening and closing of the valves, alternately, in pairs. When the piston is at the top of the cylinder, the upper steam valve and the lower exhausting valve are to be opened, while the lower steam valve and the upper exhausting valve are to be closed. When the piston is at the bottom of the cylinder, this process is reversed.

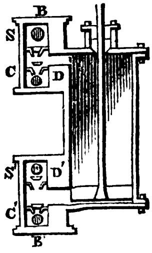

Fig. 16.

39. *Connexion of the Piston-Rod and the Beam.*—In the *single acting engine*, the pressure of the steam acts on the piston only during its *descent*, its *ascent* being effected by a counter-weight attached to the further extremity of the beam; it is sufficient for this purpose, that the piston-rod be connected with the beam by a flexible chain. But, in the *double acting engine*, the pressure of the steam acts on both sides of the piston, which must therefore be *pushed upward* as well as *pulled downward;* the connexion between the piston-rod and the beam by any *flexible* medium is, therefore, obviously inadmissible: a *chain* cannot communicate an *upward impulse* from the piston to the beam. To obviate this difficulty, Watt first proposed to attach to the piston an inflexible metallic bar, to the upper end of which was fixed a straight toothed rack, which should work in gear with corresponding teeth on the arched head of the beam, as shown in the adjoined figure. But this kind of jarring action was found to be incompatible with the smooth action of a piston-rod working air-tight and steam-tight through the stuffing-box of the cylinder. Watt suggested other contrivances for producing a smooth and equable motion; he adapted straps or chains to the beam and to the piston-rod, so as to secure the required movements; but these and other plans were presently superseded by the admirable mechanism which will be next described.

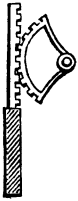

Fig. 17.

40. *Parallel Motion.*—The difficulty was, to adjust the *rectilinear* motion of the piston-rod to the *circular* motion of the beam; without such adjustment, it is evident that either the piston-rod, being forced to the right and left alternately, at each motion of ascent and of descent, would be broken or bent; or that the stuffing-box would be so injured by these derangements of action, as to cease to be air and steam-tight. The contrivance by which these difficulties were removed by Watt, is one of the most happy

inventions ever introduced into machinery. It has been termed the *parallel motion;* its mechanism may be understood by means of the subjoined figure. B represents the end of the beam, which is *pulled downward,* and *pushed upward,* by the motion of the piston-rod R P; the motion of B is in the direction of the dotted *curve;* that of R P is *rectilinear.* To adjust these counteracting motions, a series of bars are introduced, which are moveable on pivots, and which by the balance of their action prevent the piston from deviating to any injurious extent from the straight line.

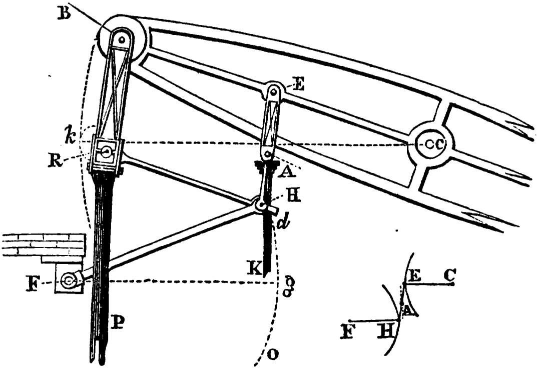

Fig. 18.

Fig. 19.

Two fixed points of support are taken, the one at F, as near as possible to the line in which the piston-rod moves; the other at C, the centre of the working beam. *Two perpendicular bars,* B R and E H, are attached to the beam at B and E; and *two transverse bars,* R H and F H, are added, the former connecting the lower extremities of the two vertical bars, the latter connecting the lower extremity of the vertical bar E H with the fixed point F; all the bars move freely on pivots at all their points of attachment. The head of the piston-rod is connected with the pivot at R. The diagram, fig. 19, relates to paragraph 41.

The *action of this machinery* is as follows. 1. Let us imagine the end of the beam B to *descend* in the direction of the dotted curve. During its progress to the *horizontal position*, indicated by the dotted line *k* C, it is continually pushing the perpendicular bar B R outward; and this effect, if not counteracted, would disturb the rectilinear course of the piston-rod. But this *outward push* of the bar B R is counteracted by an *inward pull* by the rod R H upon the point R; the end H of the rod R H is preserved at a proper distance from the line of motion of the piston-rod, by means of the rod called the *radius rod*, H F, which is attached to the fixed point F; and the rod H F, being thus fixed, describes, with its extremity H, the curve *d g*, which is directed inwardly, and counteracts the outward direction of the curve described by B. Hence it follows, that the top of the piston-rod R moves in a direction almost vertical. It is correct to say *almost*, for it is not strictly so; the deviation, however, from the vertical motion involves a minute calculation, and it is of comparatively little importance in practical operation. 2. As the beam quits the horizontal position in *completing its descent*, it is continually pushing the bar B R inward; but this *inward push* of the bar B R is now counteracted by the *outward pull* of the bar H F, which now completes the curve *g o*, and, by means of the transverse connecting bar H R, maintains the piston-rod in its nearly vertical direction. 3. It is obvious, that during the *ascent* of the beam, the same movements of the bars will secure the vertical ascent of the piston-rod. This beautiful contrivance represents, in fact, a kind of jointed parallelogram, three of the angles of which describe curves, while the fourth, which is connected with the piston-rod, moves nearly in a straight line.

41. *Motion of the Air-Pump Rod.*—The same machinery which regulates the motions of the piston-rod of the cylinder, also regulates those of the pump-rod. In the preceding figure 18, the upper part of the *air-pump rod* is represented at A K; it is connected at the top to the middle of the bar

E H, where it works freely on a pivot A. This machinery may be readily understood by means of figure 19, in which the bars composing it are separated from the beam, the letters being preserved precisely as in figure 18. C E and F H are two bars, working on pivots at the fixed points C and F, and describing curves at their free extremities. The bar E H connects these free extremities, upon which it moves by pivots. From the antagonising action of the two transverse bars, it follows, that the point A, the head of the air-pump rod, will move in a nearly vertical direction.

42. *Nature of the Crank.*—It has been shown that the alternate motions of the piston-rod, determined by the *double acting cylinder*, are communicated to the working end of the beam, to the curved motion of which they are adjusted by the contrivance of the *parallel motion.* The next object was to convert the *rectilinear* motion, thus produced, into a *rotatory* motion. So long as the force of steam was employed for the mere purpose of raising water, no such motion was wanted; but when its application was required for the purposes of turning the wheels of mills—of giving effect to the machinery of cotton manufactures and printing presses—of propelling steam vessels and other locomotive engines—it became necessary to impart a new direction to its operation. The action of the *sun and planet wheels*, in producing a circular motion, has been already explained; this machinery was employed, under peculiar circumstances, for a time by Watt, but was abandoned by him, so soon as he was enabled to introduce into his engines the more successful action of the *crank.* The simplest idea of a crank is that of the *handle to a wheel;* its action is familiarly illustrated in the process of drawing water from a well: the bent handle attached to the wheel is first pushed out, then pulled in the opposite direction, and thus a continued rotatory motion is produced upon an axle. The application of this principle to the steam engine, and the variations of pressure on the crank of a steam engine, may be conveniently illustrated by curves. This will be readily perceived in the following

figure, which represents the lower portion of the connecting-rod, which works at its upper extremity on a pivot connected with the working extremity of the beam, as may be seen more completely in the engraving at the end of this chapter. The lower extremity of the rod is connected by a moveable joint at I with the lever I K. The centre or axis, to which the rotatory motion is to be communicated, is indicated by the letter K. Hence it would appear, that as the connecting-rod moves upward and downward, it would carry the lever I K round the centre K, so as to occupy successively the positions denoted in the figure by the dotted shadows of the lever; and thus a continued rotatory motion would be communicated to the axis.

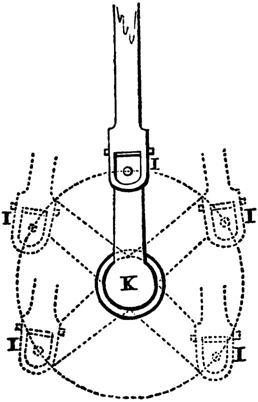

Fig. 20.

43. *Irregular Action of the Crank.*—On considering more closely the action of the crank, it will be found to be by no means continuous in its motion. There are *two positions* which the crank assumes in its circuit, in which the moving power has positively no effect whatever in communicating a rotatory motion to it. 1. *When the piston is at the bottom of the cylinder*, the crank will be in the position denoted in the preceding figure: the joint I will be in a perpendicular line between the upper end of the connecting-rod and the centre K. It is obvious, that as the piston ascends in the cylinder, the connecting-rod will tend to push the joint I, not to the right nor to the left of the dotted circle, but *directly downward* upon the axis K. 2. *When the piston is at the top of the cylinder*, the crank will have performed half a revolution, and the joint I will be in a perpendicular

line below the centre K. As the piston descends, the connecting-rod will tend to pull the joint I, not to the right nor to the left of the dotted circle, but *directly upward* upon the axis K. It is evident, that if in either of these positions, the action of the crank were for a moment to cease, it would be out of the power of the piston to put it again into motion. 3. Another difficulty connected with the crank, is the *inequality of its motion.* In two positions, it has been shown to be actually stationary. There are also *two positions*, in which its action is most energetic; and it becomes feebler in proportion as the crank moves from these points towards the two stationary positions above described. Let the reader once more direct his attention to the process of drawing water from a well; let him imagine his own arm to be the connecting-rod, and the handle of the wheel the crank; he will find that his force is most effective, when the angle described by his arm upon the crank is a *right angle;* and that his force will become less effective, as the angle of leverage becomes smaller or greater. The application of this simple illustration to the crank of the steam engine is obvious; and the result of it is a variable, instead of a uniform, unremitting action. In the following paragraph, a remedy for these inconveniences will be described.

44. *Nature of a Fly-Wheel.*—In impelling machinery by force, it is frequently necessary that *the force should be regulated.* This necessity may arise from several causes. There may be a want of uniformity in the *first moving power*, as in the Single Acting Engine, already described, in which the *descent* of the piston is effected by the pressure of steam, while its *ascent* is effected by a totally different means. Or, there may be a want of uniformity in the *resistance* which the force has to overcome, as in the *crank* described in the preceding paragraph. To regulate these inconveniences and equalise the motion, a large heavy wheel, called a *fly-wheel*, is connected with the machinery, so as to receive its motion from the impelling power, to keep up the motion by its own inertia, and distribute it *equally* in all

parts of its revolution. If the moving power slackens, the fly-wheel impels the machine forward; if the power tends to impel the machine too fast, the fly-wheel slackens it. The object of the fly-wheel, therefore, is to absorb, as it were, the surplus force at one part of the action of the machine, and to give it out when the action of the machine is deficient; by Leslie it was well compared to a "reservoir which collects the intermittent currents, and sends forth a regular stream." On this subject a writer in the Penny Magazine observes, that the "fly-wheel may be considered as occupying the point of connexion between the *production* and the *consumption* of steam power. All the complex arrangements relating to the production and management of the steam have performed their wonted part when the fly-wheel is set in motion; and we may dismiss the steam engine from this point, and regard the fly-wheel as a mighty workman, whose labours may be directed to the roughest as well as to the most delicate operations,—to the production of a cotton gown, a shilling, a Penny Magazine; a workman to whom small things cease to be small, and great things cease to be great."—*New Series*, 1841.

45. *Connexion of the Fly-wheel with the Crank.*—In order to equalise the motion of the crank, Watt attached a *fly-wheel* to its axis, as represented in the plate at the end of this chapter. This wheel is made of large diameter, in order that its circumference may revolve rapidly; it is of great weight, being made of lead or iron, that it may acquire considerable momentum so as to render the motion as uniform as possible; and it is so nicely placed upon the axis, as to be almost free from friction, and thus enabled to communicate its motion to the axis, when this is required from the irregular action of the crank. The objects of the fly-wheel in the steam engine, as here described, are obviously twofold: first, to extricate the machine from the mechanical difficulties which occur at the *two stationary positions* of the crank; and, secondly, to equalise the effects of the varying leverage by which the first mover acts on the crank.

But besides the irregularity in the action of the crank, there are other causes which, in the absence of a fly-wheel, would disturb the uniform velocity of the engine: there are *variations of resistance*, and of *power*. The resistance which an engine has to overcome, particularly in manufactures, is continually liable to vary; it may be very great one hour, and very small the next. When the *resistance is diminished*, or the moving power increased, the excess of force is expended on the fly-wheel, to which a proportional momentum is communicated with little increase of velocity. When the *resistance is increased*, or the moving power diminished, the momentum accumulated in the fly-wheel continues the motion with little diminution of its own velocity. It is not, however, pretended that the equalisation of force produced by the fly-wheel, is perfect; but it is sufficient for ordinary purposes; and its efficiency will be proportioned to the mass of matter in the circumference of the wheel and to the square of the wheel's velocity. The next step in the progress of improvement was to regulate the velocity of the fly-wheel.

46. *Use of the Governor.*—It occurred to Watt that the velocity of the fly-wheel might be regulated by *increasing or diminishing the supply of steam to the cylinder*, as the occasion might require: if the wheel went too fast, the supply should be limited; if too slow, it should be increased. With this view, he adapted to the engine an ingenious piece of mechanism, which had been previously employed in regulating the machinery of mills, and which, from its characteristic effect, is called the *Governor*. This contrivance consists in a kind of conical pendulum, connected on the one hand with the axis of the fly-wheel, and on the other with a *throttle valve*[*] in the steam pipe. In the following

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[*] The various kinds of valve employed in steam engines will require a separate notice. They will be arranged, illustrated, and severally described, in Chapter VII. The *name* of the valve here used suggests its purpose: the steam tube is *throttled* by it.

figure, two balls B B are suspended at x by inflexible bars from an axis or spindle, which is made to revolve by means of a rope connected with the axis of the fly-wheel, and working in the grooved wheel G of the spindle; the velocity of the fly-wheel may therefore be estimated by that of the grooved wheel of the spindle. The two bars are prolonged from the centre x to k k, where they are connected by moveable joints with two short levers, the upper extremities of which are fixed to a moveable socket y, which slides up and down the spindle. This socket is one of the extremities of a straight lever y p, which is connected by moveable joints with two other levers, so as, entirely or partially, to open or close a valve v within the steam-pipe. If the fly-wheel move too slowly, the two balls collapse, the angles at k k become proportionably obtuse, the socket y is forced upward, the extremity p of the lever is forced downward, and the valve v is opened for the admission of more steam. On the other hand, if the fly-wheel move too rapidly, the balls fly off from the axis of the spindle, by the centrifugal force, assuming the position of the dotted balls B' B' in the figure; the angles at k k become proportionably acute, the socket y is pulled downward, the extremity of the lever p is forced upward, and the valve v is closed against the admission of steam. Such is the general principle of the Governor; different modes of combining the several parts are adopted by different engineers.

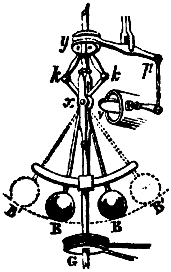

Fig. 21.

47. *Connected view of the Double Acting Engine.*—We are now in a condition to understand the relation which the several parts of the Engine, already separately described, bear to each other. In its general construction it resembles the Single Acting Engine, described and figured in the preceding chapter, but it differs in several important features. Among these are, its capability of performing twice the

amount of work in the same time, from the simultaneous action of the pressure, and of the condensation of steam, at *each ascent and descent* of the piston; its near approximation to uniformity of power; its economy of heat, and consequently of fuel, by the diminution of cooling surface; and its reduced bulk. In the following engraving, taken from the valuable work of Tredgold, a section of this engine is illustrated; a few additional remarks to those which have already been made on its separate details, will serve to explain its general operation:

(1.) At the right is seen the great horizontal *steam tube* S, which admits steam into the cylinder through the *throttle valve*, which appears near S in the form of a disc. The boiler is omitted in this plate, but its connexion with the tube, and the means by which it is supplied with warm water, may be seen in the Single Acting Engine, p. 40.

(2.) The *double acting cylinder* C, its two steam boxes and four valves, and the apparatus for working the valves, are the next objects which claim attention. The piston is at the top of the cylinder. The upper steam valve *a* is, therefore, represented as open for the admission of steam, the upper exhausting valve *c* as closed; the condition of the two lower valves is reversed. The operation of opening and closing these four valves is effected by a series of levers, terminating in one handle or *spanner*, which is worked by two pegs attached to the pump-rod R. Before the piston arrives at the bottom of the cylinder, the upper peg strikes the handle of the levers downward, and in a moment reverses the condition of the four valves. The steam from above the piston then rushes down through the perpendicular tube S, issues at the lower steam valve *d*, which will now be open, and forces up the piston; but, before the piston arrives at the top of the cylinder, the lower peg strikes the handle of the levers upwards, the condition of the valves is again reversed, the steam below the cylinder rushes through the lower exhausting valve *b* into the condenser B, and the *stroke* of the engine is repeated.

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(3.) In the *condenser* B, the steam meets with a *continual* jet of cold water. In the single acting engine, the process of condensation is suspended during the descent of the piston, and the injection accordingly intermits during this interval; but in the double acting engine, condensation goes on equally during the descent and ascent of the piston, and the condensing jet is therefore incessantly at play. The variations which occur in the velocity of the piston (which will be noticed in the following chapter), and the consequent variations in the quantity of steam discharged into the condenser, require corresponding variations in the quantity of condensing water; its amount is, therefore, regulated by the injection cock I, which is worked by a lever and handle. The water produced by condensation of the steam is removed by the *air-pump* A, and carried into the warm cistern, from which a portion of it is drawn by the pump L, and conveyed to the boiler, as shown in the engraving of the Single Acting Engine. The cistern containing the condenser, the air-pump, and the injection cock, is supplied with water by the pump N, on the left side of the beam.

(4.) On the extreme left is seen the *fly-wheel* P, on the axle of which is fixed the *crank*; and this is attached by the connecting-rod O with the working extremity of the beam *h*. Behind the connecting-rod is seen the *governor*; this is connected by bevelled wheels with the fly-wheel, and it regulates, by a series of levers, one of which is seen at R, the throttle valve in the steam tube S.

(5.) On the right extremity of the beam is seen the apparatus which produces the *parallel motion*. The moving parallelogram is represented at *f b d g*; the rod *d c* is the *radius rod*: it terminates the arc of the circle through which the point *d* travels. At *e* is seen the extremity of the pump-rod R, which is worked by the same machinery as that of the parallel motion.

(6.) Returning to the left side of the beam, we find the *pumping apparatus*. D represents the barrel of the pump, and M is the pump-rod, which is connected with the beam by mechanism similar to that of the parallel motion, already described. When the piston of the pump descends, the water is forced upward through the pipe G, and conveyed by appropriate channels to a distance and height proportional to the power of the engine. The barrel of the pump is filled through the pipe F by means of machinery adapted to this purpose below; and, when the piston of the pump ascends, the valve at the left of the barrel opens, and the water rushes through in the same direction as that from the pipe G. The supply for the descent of the piston will rush in at the bottom valve from F, and be raised through the pipe G, as before. The valves with which the piston of the air-pump is furnished are termed *clacks*. They will be noticed under the article *Valve* in Chapter VII.

RECAPITULATION.

35. Describe the advantages which the *Single Acting Engine* of Watt possessed over the *Atmospheric Engine* of Newcomen, with regard to the capability of increasing or diminishing the power; to the economy of heat; to the method of rendering the piston air-tight; and to the mode of condensation. In what respect were both engines defective?—36. Explain the construction of the *sun and planet wheels*, and their operation in converting a reciprocating into a circular motion. What is the advantage, and what are the disadvantages, of this mechanism?—37. What is the principle of the *Double Acting Engine* of Watt?—38. Explain the construction of the double acting cylinder, with reference to the steam boxes, and their valves. In what order are these valves worked during the performance of the engine?—39. In what does the connexion between the piston-rod and beam differ in the single, and in the double acting engine? What is the cause of this dif-

ference? By what mechanism did Watt first propose to connect the piston-rod with the beam? What was the defect of this mode?—40. By what contrivance did Watt eventually adjust the *rectilinear* motion of the piston-rod to the *circular* motion of the beam? Explain generally the mechanism of the *parallel motion.*—41. How is the air-pump worked in the double acting engine?—42. What is a crank? Give a familiar illustration of the working of a crank. Explain the position of the crank in the steam engine. What is its action?—43. Point out the irregularities in the action of the crank; and the inequality of its motion.—44. What is the object of a fly-wheel generally? From what sources does irregularity of force occur in the operation of machinery? How does a fly-wheel regulate the force of machinery?—45. To what part of the steam engine is the fly-wheel attached? What are the *particular* objects of the fly-wheel in the steam engine? How does the fly-wheel compensate for the variations of resistance, and of power, to which an engine is liable? How far is a fly-wheel effective in equalising the force of the engine? —46. By what contrivance is the velocity of the fly-wheel regulated? Explain, generally, the construction of the *governor?* Describe its peculiar action.—47. What are the most important features in the double acting engine? Describe the several parts of the engine as illustrated in the plate, according to the order of description in this paragraph.

CHAPTER V.

APPLICATIONS OF THE EXPANSIVE FORCE OF STEAM.

DOUBLE CYLINDER ENGINES.

48. *Discovery of the Expansive Force of Steam.*—It has been incidentally remarked (p. 61), that the velocity of the piston is unequal at different parts of its stroke. This would appear to be the natural result of a heavy body descending into a vacuum. When the piston is at the top of the vacuous cylinder, and steam is admitted above it, the piston *begins to descend*, its own inertia and its friction against the cylinder being the only impediments to its descent. As the piston *continues to descend*, its own inertia favours its motion; the steam having, thus, less resistance to overcome, presses the piston down with increased velocity. As the piston *completes its descent*, its velocity will obviously be still more increased. It occurred to Watt that this *surplus* force might be economised, and a moving power obtained in addition to that produced by the stroke of the piston. In 1769, he alludes to "a method of still doubling the effect of the steam, and that tolerably easy, by using the power of steam rushing into a vacuum, at present lost. This would do little more than double the effect, but it would too much enlarge the vessels to use it all; it is particularly applicable to wheel engines, and may supply the want of a condenser, where the force of steam only is used; for open one of the steam valves, and *admit steam until one-fourth of the distance between it and the next valve is filled with steam, then shut the valve, and the steam will continue to expand, and to press round*

the wheel, with a diminishing power, ending in one-fourth of its first exertion. The sum of the series you will find greater than one-half, though only one-fourth of steam was used. The power will indeed be unequal, but this can be remedied by a fly, or by several other means." Upon this principle, the motions of the piston are effected, partly by its own inertia, and partly by the expansive force of a certain quantity of steam insulated in the cylinder.

49. *Watt's application of the Expansion of Steam.*—The application of the *expansive force* of steam, as a moving power, will be readily understood by being illustrated in a particular case. If a piston, loaded with a weight of one ton, can be raised to a height of four feet, in a cylinder filled with steam at the ordinary pressure of one atmosphere, it follows that the same piston, loaded with a weight of four tons, can be raised to a height of one foot, in a cylinder *one-fourth* full of steam of four times the ordinary pressure. The following figure represents a cylinder and piston in this condition: the piston is raised one foot by steam of the pressure of four atmospheres. *Let the supply of steam be now cut off.* The piston will continue to rise in the cylinder, by the *expansive force of the steam* beneath it, though with a gradually diminishing force. When the piston has been raised a second foot, or has reached the point indicated by the figure 2, on the left of the cylinder, the volume of the steam has been doubled, and its pressure is reduced to

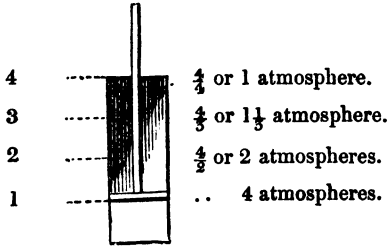
4
3
2
1
$\frac{4}{4}$ or 1 atmosphere.
$\frac{4}{3}$ or $1\frac{1}{3}$ atmosphere.
$\frac{4}{2}$ or 2 atmospheres.
.. 4 atmospheres.

Fig. 22.

that of two atmospheres, as indicated by the figures on the right of the cylinder. When the piston has been raised a third foot, the volume of the steam has been trebled, and its pressure is further reduced to that of one atmosphere and a third. When the piston has been raised the fourth foot, the volume of the steam has been quadrupled, and its pressure is that of one atmosphere, or of what is commonly called low-pressure steam. Throughout this process, therefore, the piston has been raised three feet by means of a force gradually diminishing from a pressure of four to that of one atmosphere, without any additional expenditure of steam, but simply by the expansion of a certain quantity of steam which had already produced its usual effect. In reference to the economy of employing the force of steam, *expansively*, Watt states, that when the steam is cut off at one-fourth of the descent of the piston,—"when only one-fourth of the steam necessary to fill the cylinder is employed, the effect produced is more than one-half of the effect which would have been produced in filling the whole cylinder full of steam, by admitting it to enter freely above the piston during the whole course of its descent." Watt stated, that the advantage of this method of working a steam engine increases in proportion as the supply of steam is sooner cut off, but that the increase is not great after the steam has been rarefied four times; that the engine becomes more manageable, and is more easily adapted to every variation in its task, and all its powers are more easily computed. Thus:—

Let the steam be cut off at	Its performance is multiplied
$\frac{1}{2}$	1·7
$\frac{1}{3}$	2·1
$\frac{1}{4}$	2·4
$\frac{1}{5}$	2·6
$\frac{1}{6}$	2·8
$\frac{1}{7}$	3·0
$\frac{1}{8}$	3·2

The *expansive principle* was adopted in 1776, at the Soho Manufactory, Birmingham; soon afterwards at the Shadwell Water-works, and at several other places. The application of the principle was, however, limited in Watt's engines, owing to his employing steam of low pressure, and cutting it off after the piston had performed from half to two-thirds of its stroke; the effect of this was little more than to admit of the piston exhausting its velocity by the time it had reached the bottom of the cylinder. The operation of the expansive principle in the Cornish Engines is much more effective; in these, steam of the pressure of four atmospheres is employed, and its supply cut off at one-fourth of the stroke of the piston, as in the preceding figure.

50. *Hornblower's application of the Expansive Principle.*—In 1781, Jonathan Hornblower obtained a patent for a new mode of applying the expansive force of steam. This plan, had it been carried into effect, would have combined two advantages over that of Watt: first, it would have produced a more equable method of employing steam; and, secondly, it would have rendered steam of high pressure available in small cylinders at less risk. Watt had discovered, that when steam is confined above the piston in a cylinder, and a vacuum exists below it, the expansive force of the steam will continue the motion of the piston, till an equilibrium is produced between the moving power and the resistance arising from friction, &c.; and that, by this means, a force is obtained beyond that of the ordinary pressure of the steam. Hornblower proposed to use *two cylinders* of unequal sizes, attached to the same beam, and so connected together by pipes, that, after the steam had performed its ordinary effect in the one cylinder, it might *expand into the other* with a diminishing force, and thus act at the same time upon two pistons. This contrivance is represented in the following figure. A and B are two cylinders, with their pistons. The *smaller cylinder* is supplied with steam from the boiler by the pipe F; the steam is admitted to, or cut off from, the upper part of the piston by the valve G. The

steam tube H connects the upper and lower parts of the smaller cylinder, the steam being admitted or cut off by the valve I. The lower part of the smaller cylinder is connected with the upper part of the *larger cylinder* by the bent steam tube K; the valve L admits or prevents the supply of steam from the former to the latter. The steam tube M communicates between the upper and lower parts of the larger cylinder, and is provided with the valve N. The tube P leads to the condenser, and is furnished with the valve O. Thus we have a series of passages and valves by which steam is admitted into, and allowed to escape from, both cylinders at the proper periods. Let us now consider the action of these cylinders during each part of the stroke of the piston:—

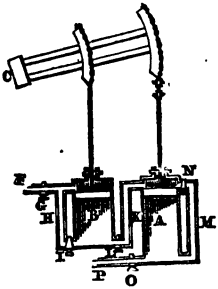

Fig. 23.

(1.) In figure 23, *the pistons are at the top of the cylinders*. The piston-rods are connected with two arched heads of the beam, at a distance from each other corresponding with the length of the cylinders, so that both may act together at each ascent and descent of the beam. Let both cylinders be supposed to have been 'blown through,' filled with steam, and their valves closed. Let the valves G, L, and O, be opened, as represented in this figure; the steam will then rush into the condenser from the larger cylinder, which will become vacuous; steam will enter through G, and press down the piston in the smaller cylinder; the steam beneath this piston will thus be forced through the tube K into the upper part of the larger cylinder, and press down its piston, so that both pistons will descend at the same time. It is important here to advert to the *different pressures of the steam in the two cylinders:* in the smaller cylinder, the pressure of the steam is continually *increasing*, owing to its unintermitting supply from the boiler *above* the piston, and to the gradual expansion of the steam *below* it into a larger bulk; whereas, in the larger cylinder, the pressure of the steam is continually *diminishing*, owing to the gradual expansion of the steam *above* its piston into a larger bulk, and to the space *beneath* it being vacuous. The force, therefore, which presses down the piston in the smaller cylinder, is the result of the excess of the *increasing pressure* of the steam in this cylinder over the *diminishing pressure* of the steam in the other. This difference of pressure in the two cylinders is adjusted by their difference of size.

(2.) In figure 24, *the pistons are at the bottom of the cylinders*. The conditions of the valves are now reversed: G, L, and O, are represented as closed; I, and N, as opened. By the closure of the three valves, no steam can enter into the smaller cylinder from the boiler, no steam can escape from the larger cylinder into the condenser, nor can steam pass from one cylinder into the other. By opening the two valves, the steam communicates from the upper to the lower part of the piston in each cylinder; the pistons are thus in a state of equipoise, and are drawn to the top of the cylinders by the means of counterweights attached to the pump-rods, as in Watt's Single Acting Engine (page 40). When the pistons have reached the top of the cylinders, the condition of the valves is again reversed, and the stroke repeated. The effect anticipated from Hornblower's method, was nearly the same as that produced by Watt's plan of cutting off the steam before the end of the stroke. Hornblower appears not to have intended to use steam of high pressure.

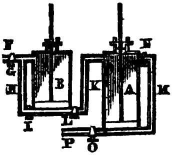

Fig. 24.

51. *Woolf's application of the Expansive Principle.*—In 1804, Arthur Woolf obtained a patent for combining the use of the double cylinder engine of Hornblower with the condensing apparatus of Watt. The novelty of his claims consisted in the assumption of a new law of the expansibility of

steam. He imagined that he had proved, by experiment, that high-pressure steam will expand to the extent of doubling its original volume for every pound of pressure above that of the atmosphere, and still retain an elastic force equal to that of the atmosphere, the temperature being unaltered; and, hence, that steam, generated at a pressure of fifty pounds on the square inch, will expand to fifty times its bulk, and still retain a pressure of fifteen pounds, or that of the atmosphere. But these statements are at variance with the established law of the expansion of fluids. It is well known, that the temperature being unaltered, *the volume of elastic fluids is inversely as their pressure;* and that, consequently, steam generated at a pressure of fifty pounds, will expand only to four times and a fraction of its bulk, assuming the pressure of the atmosphere to be fifteen pounds on the square inch.

52. *Cartwright's Single Acting Engine.*—In 1797, Dr. Edmund Cartwright obtained a patent for a new and ingenious mode of constructing the steam engine. The only novelty in this machine is the introduction of a *metallic piston*, which was formed by rings of metal pressed from within outwardly against the cylinder, so as to be rendered air-tight without the employment of the usual means (see chapter VII.) Among the results anticipated from the new arrangement, was the substitution of alcohol for water; for, as the vapour by which the engine was to be worked would *circulate* through the machine without material loss, one supply of alcohol would be sufficient to keep the engine at work, and it was supposed that this would require only half the quantity of fuel usually employed. Cartwright's engine is represented in the opposite figure. Steam is conveyed from the boiler to the cylinder by the steam tube B, a portion only of which is seen in the figure. There are two valves, the steam valve, T, and the piston valve, R; these are of the sort called *spindle valves* (see chapter VII.), and are contrived so as to work themselves. D is a pipe which conducts the steam from the cylinder to the condenser. The

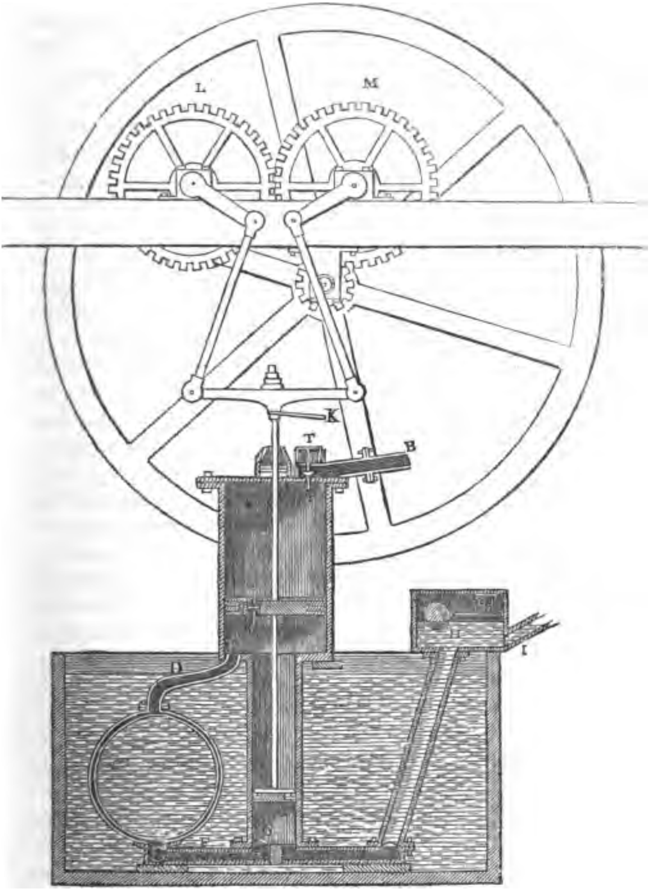

Fig. 25.

condenser consists of two cylinders, nearly of the same size, placed one within the other; the water of the cistern fills the inner cylinder, and surrounds the outer one; the steam occupies the narrow space between them, and is condensed by contact with the cold surfaces. The air-pump is placed directly below the steam cylinder; its piston-rod is connected with the piston of the cylinder. F is a pipe leading from the condenser to the air-pump; from this pipe the condensed steam passes through the valve G into the pump-barrel, whence it is forced into the hot cistern H, which is furnished with a valve for regulating the quantity of air, and a pipe I for supplying the boiler. The action of this machinery is very simple. 1. Let us suppose *the piston to be at the top of the cylinder*. In reaching this position, it strikes the tail of the steam valve T upward, and opens it for the admission of steam; at the same time, the stem of the piston valve R strikes against the upper part of the cylinder, and the valve is firmly closed, so as to prevent the escape of steam from the cylinder. 2. Let us now suppose *the piston to be at the bottom of the cylinder*. A projecting spring K, attached to the piston-rod, strikes the stem of the steam valve T, and closes it against the supply of steam; at the same time, the tail of the piston valve R strikes against the bottom of the cylinder, by which means the valve is opened, and the steam escapes from above the piston into the condenser. 3. The valve in the *hot cistern* opens inwardly; it is connected with a ball, which floats on the surface of the water. When the air accumulates in too great quantity, it presses on the surface of the water; the level of the liquid falls, the ball falls with it, and the valve is opened for the escape of the air. The pressure of the air drives the water into the boiler, which is thus supplied unceasingly by the engine. 4. The *descent of the piston-rod* is effected by the pressure of steam which rushes in by the valve T; its *ascent* is secured by the momentum of the fly-wheel. On the axis of the fly is fixed a small-toothed wheel, which works in gear with a larger-toothed wheel, M; and this is connected by means of a crank to one extremity of a transverse bar attached to the head of the piston-rod. At the other extremity of the transverse bar, are fixed a similar crank and wheel, L. The fly-wheel receives its impulse during the descent of the piston, which it raises at each stroke by the momentum thus acquired. The construction of Cartwright's metallic piston will be described in a subsequent chapter.

RECAPITULATION.

48. Explain the inequality of velocity in the piston. How did Watt propose to avail himself of the surplus force thus produced? Upon what principle may steam be used, *expansively*, as a moving power?—49. Illustrate the principle by describing the motion of a piston in a cylinder. In what ratio is the motion of the piston *diminished* with the progressive expansion of the steam? What is the amount of effect gained by the use of the expansive force of steam? By what means may the greatest effect be produced in this mode of employing steam? How was the efficiency of this method limited in Watt's engines?—50. What advantages were proposed in Hornblower's application of the expansive principle? What novelty was suggested by him in the construction of the steam engine? How did he propose to apply the expansion of steam in his double cylinder? Explain the action of the *two cylinders*. What is the difference of pressure exerted by the steam in the two cylinders? What is the cause of this difference? What was the amount of effect anticipated from Hornblower's plan, as compared with that of Watt?—51. State the *law* of the relation which subsists between the volume, and the pressure, of elastic fluids? Explain the erroneous view of Woolf on this subject.—52. What novelty was introduced into the steam engine by Cartwright? Explain the principle of his engine. How are the valves worked?

CHAPTER VI.

OF THE SEVERAL PARTS OF THE MODERN STEAM ENGINE.

53. *General Remarks.*—In the four preceding chapters, the attention of the reader has been mainly directed to the labours of Savery, Newcomen, and Watt, in perfecting a *stationary* engine for a specific purpose. Numerous contrivances for applying steam to the production of mechanical power, have been from time to time introduced; many of these have been hitherto omitted, as having no direct applicability to the steam engine of the present day; they will, however, be incidentally noticed in the subsequent chapters. We are now in a condition to advert to the *locomotive* engine of modern times, as employed for land, or marine, transport. There are two kinds of steam engine in general use—the *high-pressure engine*, and the *low-pressure engine*. The former of these is sometimes termed the *non-condensing engine*, owing to the absence of a condensing apparatus; the steam, in this case, instead of being condensed, is discharged from the engine into the atmosphere, after having performed its task; the latter, or low-pressure engine, is also termed the *condensing engine*, from the presence of the condensing apparatus. The high-pressure engine is obviously the more simple of the two, its essential parts being only two in number, the boiler and the cylinder; whereas, the low-pressure engine requires the presence of a third part, the condenser. Engines are sometimes employed, which combine the principles of both these engines, being

worked by high-pressure steam, which is condensed instead of being discharged. In pursuing this subject, the several parts of the modern steam engine, and their modifications, will be first described; their combinations, and relation to each other, in the entire engine, will be illustrated afterwards. Some preliminary observations will be made on the nature of combustion and combustibles, and of high-pressure steam. As it will now be necessary to enter into more minute details than heretofore, a *tabular view* of the contents of this chapter may be found useful:—

1. *Of Combustion and Combustibles.*
    1. *Supply of oxygen.*
    2. *Supply of atmospheric air.*
2. *Of High-Pressure Steam.*
    1. *Pressure by pounds.*
    2. *Pressure by atmospheres.*
3. *Of Safety Apparatus.*
    1. *Safety valves.*
    2. *Fusible plugs.*
    3. *Steam gauge.*
4. *Of Steam Boilers.*
    1. *Extent of surface.*
    2. *Capacity for steam.*
    3. *Capacity for water.*
    4. *Forms of boilers.*
    5. *Strength of boilers.*
    6. *Materials of boilers.*
    7. *Deposits on boilers.*
    8. *Feeding apparatus.*
5. *Of Self-regulating Furnaces.*

54. *Of Combustion and Combustibles.*—The term *combustion* denotes the combination of oxygen with some other body, attended by the evolution of heat and light; the latter body is called a *combustible*, or a body capable of being burned; if employed for producing heat alone, it is called

fuel. There are various substances which, when heated to a certain temperature depending on their nature, begin to give out heat, and continue to do so until the whole of the substance be *burned*, or, philosophically speaking, be changed into new products, which, being principally gaseous, are, under ordinary circumstances, dissipated in the atmosphere. The *amount of heat*, emitted during combustion, varies with the substance burned; it is, however, definite, and may be measured; the plans usually adopted for this purpose, are, to melt ice, to raise water from the freezing to the boiling point, or to convert water into steam. The amount of heat emitted, appears to be in proportion to the *amount of oxygen* which combines with the combustible body: the greater the quantity of oxygen consumed, the greater quantity of heat is developed. The following table shows the amount of heat emitted by burning four substances of variable quantity with an equal quantity of oxygen: the amount is nearly the same:—

		lbs. of water
1 lb. oxygen	with hydrogen heats from 32° to 212° .	29½
"	with charcoal	29
"	with alcohol	28
"	with ether	28½

Tredgold states that the *average heat* for the production of effect is about 1200°; and, in order that the fuel and its products may remain in this temperature until they shall be consumed, the following circumstances must be attended to:—

(1.) A quantity of air sufficient to supply the oxygen required for combustion, must have as free access as possible to all the parts of the burning mass, and with as little exposure of the surface of the mass to the cooling effect of other air, as the draught of the chimney will allow.

(2.) The quantity or mass of fuel in combustion, must be of such a proportion to the quantity and temperature of the surface to which it communicates heat, that it can only lose as much heat as it generates when it arrives at the best temperature for combustion; allowing for the cooling effect of the surface acted on by the air required in the process.

(3.) The flame and smoke must be kept in contact with the vessel, as long as it is capable of affording heat.

(4.) The fluid to be evaporated should enter so as first to receive the heat where the smoke last acts on the fluid, so that there may be the greatest possible difference of temperature between the smoke and the fluid; and, consequently, that the fluid may deprive the smoke of heat, as it becomes gradually heated to the temperature of the vapour before it arrives over the fire.

55. *Supply of Air for Effective Combustion.*—The different kinds of fuel require different quantities of oxygen for their effective combustion. The *amount of oxygen* required for the combustion of the different kinds of *coal*, varies from nearly two to three pounds of the gas for each pound of the fuel. Oxygen constitutes about one-fifth of atmospheric air, and twelve cubic feet of oxygen are required to weigh one pound. Hence, sixty cubic feet of common *air* are required to yield one pound of *oxygen*. But Tredgold states that it is not possible to render the whole of the air effective; that part of it will escape unchanged by combustion; that he usually considers only two-thirds to be effective; and that, therefore, ninety cubic feet of air are required to yield one pound of oxygen. It appears, from his calculation, that the quantity of air and smoke may be stated in round numbers, for coal and coke, at 2000 cubic feet for each cubic foot of water converted into steam, and for wood at 4000 cubic feet. The importance of this knowledge in the construction of grates for the boilers of steam engines, and in the adjustment of the draught of the chimney and ash-pit, is obvious.

56. *High-Pressure Steam.*—The method of generating ***high-pressure steam*** has been described and illustrated at page 10. Some further observations on this subject are here necessary, as it is important to be enabled to ascertain with

readiness the *amount* of pressure produced under such circumstances, in order to prevent explosion.

(1.) Let the mouth of a vessel in which steam is generating, as in the figure, be supposed to be an inch square, and a weight W of one pound laid upon it; when the elasticity of the steam is sufficient to raise this weight, it is said to have a *pressure of one pound on the square inch*. If the weight be increased to any number of pounds, the steam which is elastic enough to raise it, is said to have a pressure of a corresponding number of pounds on the square inch. The amount of pressure usually adopted in high-pressure engines, ranges from 15 to 120 pounds on the square inch.

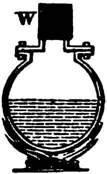

Fig. 26.

(2.) The increasing elasticity of high-pressure steam may, however, be measured, not with reference to the weight of one pound, but to that of fifteen pounds, or *one atmosphere*, upon the square inch. The attention of the reader is particularly directed to what has been said on this subject at pages 10 and 11. The pressure of steam is there measured by its effect in raising a column of mercury of 30 inches in height, which weighs fifteen pounds, within a tube. By substituting for the column of mercury another kind of weight of fifteen pounds, as in the above figure, the principle is transferred at once from Papin's Digester to the boiler of a steam engine. Supposing the weight employed in fig. 26 to be fifteen pounds, the steam which is sufficiently elastic to raise it, is said to have a *pressure of one atmosphere;* if the weight were equal to thirty pounds, it would require steam of the pressure of two atmospheres to raise it; and so in proportion. A different method of designating these pressures is sometimes adopted. Common steam, generated in open vessels, has sufficient elasticity to balance the pressure of the atmosphere, and rise against it; it is, therefore, frequently called steam of one atmosphere; consequently, when it is confined, and of sufficient elasticity to raise a weight of fifteen pounds, it is said to have a pressure of *two* atmospheres. This difference of expression is readily adjusted by specifying whether the pressure, spoken of, is the total pressure of the steam, or merely its excess above the pressure of the atmosphere.

57. *Safety Valves.*—The danger of explosion arising from the employment of steam of too high a pressure, led to the introduction of the *safety valve.* The simplest idea of this precautionary apparatus is suggested by the rude experiment described in the last paragraph but one. There are several kinds of safety valve. 1. The apparatus most commonly in use for this purpose, is represented in the figures of Savery's and Papin's engines, pages 23, 24; a safety valve is there represented as fitted in the boiler of the former, and in the boiler and cylinder of the latter, engine. This form of valve is called the *lever*, or the *steelyard, safety valve.* It consists of a conical plug, fitted to an aperture in the boiler, and retained in its seat by a weight suspended to a lever. The lever being graduated, and the weight moveable, the engineer is enabled to adapt the weight to the required pressure of the steam. For greater security, a second valve is sometimes added, with a less load upon it, so as to open first, and thus apprise the attendant of the increasing pressure of the steam. 2. In locomotive engines, in which steam of very high pressure is used, *spring valves* are employed. One of these is shown in the adjoined figure. A series of curved springs S P are arranged in pairs, alternating in opposite directions, within a square frame. These springs are made to press upon the valve *n*, by means of the transverse bar *m*, the pressure being regulated by a screw *t*. An engine should always be provided with two such valves, one of which should be enclosed in a metallic case and locked up, to prevent the

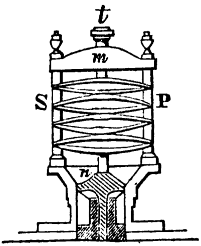

Fig. 27.

load being incautiously increased by the attendant beyond the limit of safety. 3. The *extent of surface* of the valve at its lowest part, where it is exposed to the pressure of the steam in the boiler, must be adapted to the force of the steam employed. It is obvious that it must be large enough to allow the steam to escape from the boiler as rapidly as it is generated within it. The force of the steam should be rather more than what is actually required to work the engine; in low-pressure boilers it is usually about five pounds on the circular inch; supposing, then, the diameter of the lower surface of the valve to be three inches, its area will be nine inches; and this number, multiplied by the number of pounds, gives the proper weight to be laid on the valve in an engine working at this pressure, viz., 45 pounds. The valve, so loaded, will not open, until the steam acquires a higher pressure than that of five pounds on the circular inch.

58. *Fusible Plugs.*—For high-pressure boilers, additional precautionary means against the risk of explosion have been adopted. The idea of a high-pressure engine had occurred to Leupold (page 30); it had also occurred to Watt; but it is to Messrs. Trevithick and Vivian that we are indebted, in 1802, for the practical application of high-pressure steam. To guard against the danger of explosion, Trevithick bored a hole in his boiler, and plugged it up with lead, at such a height from the bottom of the boiler, that this vessel could never be exhausted of its water by boiling without exposing the lead to be melted, and thus opening a vent for the escape of the steam. Upon the same principle, a *plug* of some *fusible metal* is tightly fastened into a hole at the bottom of the boiler, so that it may melt, and allow the water and steam to escape, whenever the temperature of the boiler rises higher than its due degree. Fusible metal plugs are liable to objections. First; their melting points are much higher than is compatible with the pressure to which the boiler is adapted: lead melts at 612°, and at this temperature the pressure of the steam would be equal to that of about 150 atmospheres; tin melts at 442°, and this tempe-

rature would correspond to a pressure of more than 25 atmospheres. Secondly; metal plugs which are fusible at the full pressure of the steam in the boiler, would become softened by the continued ordinary temperature, so as to be unfit to retain the steam at its working pressure. Various *alloys of metals* are, however, fusible at temperatures sufficiently low for the purpose; they may be formed so as to melt at temperatures ranging from 212° to upward of 600°: an alloy formed of one part of lead, three of tin, and five of bismuth, melts at the common temperature of boiling water; and by combining these metals in different proportions, alloys may be produced which melt at progressively higher temperatures. But, as Tredgold observes, we have no evidence that the melting points remain permanent in alloys which are regularly exposed to a heat so nearly approaching to that at which they fuse when newly formed. The fusible plug may be adopted as an *auxiliary* means of safety, but cannot be relied on with much confidence.

59. *Mercurial Steam Gauge.*—Another and a very different mode of ascertaining at all times the pressure of the steam, is that afforded by the *mercurial gauge.* This instrument consists of a tube bent as represented in the figure, communicating with the boiler at one extremity C, and open at the other. The tube contains some mercury, which is forced down the shorter, and up the longer, leg, by the pressure of the steam. If the tube be made of glass, a graduated scale is attached to it, as at A, and the amount of pressure ascertained by the rise or fall of the mercury. But, in high-pressure engines, a longer tube is required, and it must be made of metal; in this case, a float of

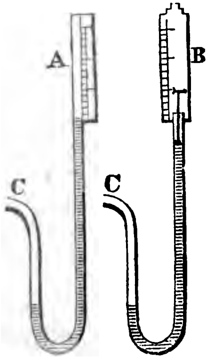

Fig. 28.

iron, fixed to a rod, is made to rest on the mercury, and the rod indicates the degree upon the scale, as at B. The *amount of pressure* is easily ascertained. If the mercury remain at the same level in both legs of the tube, the pressure of the steam in the boiler is exactly equal to that of the atmosphere. But, by calculating the weight of mercury, it has been found, that for every inch which the mercury rises above that point in the long leg of the tube, the steam in the boiler has acquired an additional pressure of nearly one pound on the square inch. Hence, if the scale be graduated by inches, each pound of additional pressure of the steam will be indicated by a rise of one degree on the scale. It is evident, that an apparatus of this kind would act as a sort of *safety valve;* for, if the pressure of the steam became too strong, it would drive the mercury out of the tube, and escape into the air. In cases in which steam of very high pressure is employed, the use of this kind of instrument would be inadmissible, owing to the great length of tube necessary to contain the required column of mercury. In these cases, the *thermometer gauge* may be employed; its principle is illustrated in the figure at page 10. A strict relation exists between the *temperature* and the *pressure* of steam, which is in contact with water, so that, by means of its temperature, as indicated to the eye by the thermometer gauge, we are enabled to judge of its pressure.

60. *Surface of Steam Boilers.*—For the effective production of steam, it is requisite, *first*, that a certain extent of surface of the boiler should be exposed to the fire; and, *secondly*, that the steam and water within the boiler should occupy relative spaces to each other. The construction of an effective steam boiler is by no means so simple a matter as it may appear. The frequent explosion of boilers has caused attention to be directed to this subject; and there is still room for considerable improvement. In order to supply steam with sufficient rapidity for the uses of an engine, it is necessary to keep a large quantity of water constantly heated; and, for this purpose, the boiler must

offer a sufficient *extent of surface* to the fire. The surface, thus exposed, may be distinguished, in reference to the effect produced on it, into the *bottom surface*, which receives the immediate effect of the fire and flame, and the *side surface*, or *flues*, which receive the heat of the smoke. 1. It will be convenient, first, to speak of the *sum* of these surfaces. Watt found, that "with the most judiciously constructed furnace, it requires 8 feet of surface of the boiler to be exposed to the action of the fire and flame, to boil off a cubic foot of water in an hour." Smeaton had previously stated the extent of surface for one bushel of coals per hour, at 88 feet; and, for 13 bushels per hour, at 82 feet. His calculation leads to the same result as that stated by Watt: it requires, in a round number, *eight feet of surface to convert one cubic foot of water into steam*. A cubic foot of water, thus converted into steam, is considered equivalent to a *one horse power*,* as employed in calculations in the present day; and a result, equal to ten times this one horse power, may thus be ensured, in the vaporisation of ten cubic feet of water, by the well-directed combustion of one bushel of coal. 2. The proportion of *bottom surface* required for the best effect, appears not to have been precisely determined; the ordinary extent ranges from three to five feet for each cubic foot of water converted into steam per hour. Tredgold states, that he has observed boilers to be incapable of supplying the proposed quantity of steam when they had less than four feet of bottom surface. Mr. Millington, who first appears to have measured the power of a boiler by its bottom surface, states that a boiler for 20 horse power is usually 15 feet long and 6 wide, having 90 feet of surface, or 4½ feet to one horse power; and that a boiler for 14 horse power has 60 feet of surface, or 4·3 feet to one horse power.

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* This expression will be fully explained hereafter. It may be sufficient, for the present, to state, that the value of the 'horse power,' in an atmospheric engine, is calculated at 33,000 lbs. raised one foot high per minute; and, on a railway, at 400 tons transported one mile per day.

61. *Capacity of Steam Boilers.*—The other requisite connected with the effective production of steam, is the *capacity of the boiler*. This vessel must be of dimensions to contain *steam* in sufficient quantity to meet the demand of the engine, without material reduction of its pressure; and *water* in sufficient quantity to supply the incessant demand for steam. 1. The *space for steam* within a boiler has been variously stated: it has been said by different writers, that a boiler should contain five, six, eight, and even ten times the volume of steam required for a single stroke of the piston; and Prony asserted, that one of the advantages of a double acting engine, consists in its requiring a smaller boiler than a single acting engine. Whatever may be the precise space for steam in a boiler, it will evidently vary with the mode by which the steam is supplied; it will be different, for instance, when the steam is supplied uninterruptedly, and when it is cut off during the descent of the piston, as in the expansive engine, described in the preceding chapter. 2. The *space for water* within a boiler varies with the more or less equable mode by which this liquid is supplied; this subject will be noticed in a separate paragraph. Tredgold states, that if a boiler be fed at every stroke, it should have five cubic feet of water for each cubic foot of steam it is capable of boiling off per hour, whether the boiler be high or low pressure. He adds, that the self-acting feeding apparatus must be delicately adjusted to reduce its intervals to even twice that time, and therefore such boilers require at least 10 cubic feet of water for each cubic foot of water boiled off per hour. He observes, that the proportion of the quantity of water in the boiler to that admitted, ought to be such that the temperature should not be lowered, so as to reduce the force of the steam one-thirtieth part. He concludes, "that to limit a low-pressure steam boiler of a double acting engine, with a self-acting feed, to a change of elastic force not exceeding one-thirtieth, we must have ten feet space for steam, and ten for water, for each cubic foot of water the boiler commonly generates

in an hour, or for each horse power; and that, if the steam be cut off before the stroke is completed, a greater space must be allowed for steam."

62. *Forms of Steam Boilers.*—The extent of surface, and the capacity for steam and water, of a boiler having been considered, it becomes a matter of considerable interest to determine what *form* of boiler is most likely to give effect to the proportions above stated. 1. In point of strength, we should naturally incline to the *spherical* form, the pressure of the steam being equal at every point of such a boiler; in fact, the earliest steam boilers were nearly of this form, as in the engines of Savery and Papin (pp. 23, 24); more recent discovery has, however, shown, that what was thus gained in strength is more than compensated for by loss of surface, and, consequently, by increased consumption of fuel. 2. Modifications of the spherical form were therefore adopted: the bottom surface was rendered concave, the flue surfaces, or sides, were perpendicular, and the upper surface retained the hemispherical shape; this kind of boiler presented a combination of the sphere and the cylinder, and may be termed the *cylindro-spherical* boiler. 3. Another modification was suggested by the loss of heat, which occurred as the flame passed up the sides of the boiler. An abrupt diminution of the diameter of the boiler was likely to confine the flames around the sides, as may be seen in the boiler of Newcomen's engine, p. 26. This is the origin of what has been called, from its characteristic appearance, the *haycock* boiler. In the following paragraphs, the principal forms of boiler adopted in more recent practice, are illustrated.

63. *Waggon Boiler.*—This form of boiler, so named from its resemblance to a long, heavy, four-wheeled *waggon*, was introduced by Watt. His object in the construction of his boilers was, to economise the fuel as much as possible. He says:—"It is not the shallowness or depth of the boiler that produces this effect; but the making of the boilers of such a shape, that the air which passes through the fire shall be

robbed of almost all its heat before it can make its escape." The boiler, as originally constructed by Watt and Bolton, was slightly concave at its bottom surface, with perpendicular sides, flat ends, and a semi-cylindrical top. The form of the sides and ends was, certainly, not conducive to strength; indeed, the steam intended to be generated in this boiler was of a pressure not exceeding that of the atmosphere by more than from 3 to 5 lbs. on the square inch. An improvement was afterwards introduced in this form of boiler, by hollowing in the sides, as represented in the transverse section of the improved *waggon boiler* in the annexed figure. The heated air from the fire below the boiler, after passing under its entire length, is brought back, previously to its escape to the chimney, by flues *o o*, in order that the sides of the boiler may receive all the effect of the heated air. The modes by which the boiler is supplied with water, will be more particularly noticed hereafter. One mode may be here described. By means of the apparatus represented in the figure, the water is supplied in proper quantity to the boiler, and maintained at a uniform level from a reservoir by means of a tube *g*, which passes through a box *c* into the boiler. The box contains a valve *v*, which is made to regulate the supply of water: when the water is at the required level in the boiler, the valve *v* is kept in its seat by pressure from the lever *a b*, which is loaded at *a*. But to the other branch *b e* of the lever, an iron rod is attached, which descends into the boiler, and carries a float of wood *f*; when the level of the water sinks, the float sinks with it, the point *e* is brought down, the valve is raised, and water admitted into the boiler.

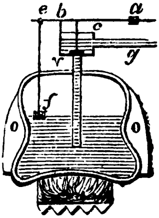

Fig. 29.

64. *Cylinder Boiler.*—Another form of the boiler is the *cylindrical.* A simple cylinder with convex ends appears to be the best form of boiler for the production of high-pressure steam. Of this form, two modifications occur: that

in which the furnace is *within*, and that in which it is *outside*, the boiler. 1. The former of these, or the *tubular-flued boiler*, is represented, in transverse section, in fig. 30. It consists of two cylinders, the one placed *within* the other, and the space between them being occupied to a certain extent by the water. The outer cylinder may be six feet in diameter, and is frequently fifty or sixty feet in length. The heated air from the fire, after traversing the inner cylinder, is conveyed under the boiler by the flues *o o*, by which means it imparts the last effects of its heat to the boiler, before it is carried to the chimney. The cylinder boiler, as figured above, is preferred as the most economical, for the great steam engines at the mines in Cornwall. The boiler employed by Smeaton was of a spherical form, but, like the one above, it was enclosed entirely within the boiler. Tredgold says, that on the large scale, Smeaton's boilers were admirably adapted for generating steam, and were little inferior to any which have since been contrived. 2. The following figures illustrate a *simple cylinder boiler*, in which the furnace is on the *outside*; the smaller figure represents a transverse, the larger a vertical and horizontal, section, of this apparatus. This kind of boiler has a diameter of four feet, and is about thirty feet in length; its ends are flattened segments of spheres; it is

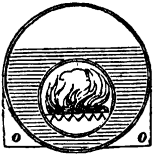

Fig. 30.

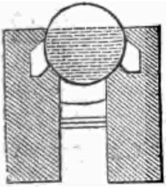

Fig. 31.

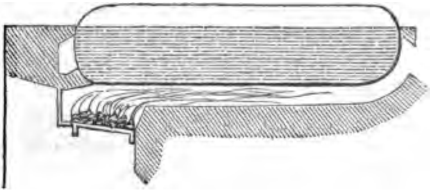

Fig. 32.

placed in the horizontal position, as in the figure. The furnace is situated below it, and encased in brickwork. By this position, the fire communicates its greatest heat to the bottom surface of the boiler; the flame and hot air then traverse the flues, the direction of which is denoted by the white channels, in a backward direction, so as to expend all their heat on the several parts of the boiler before they are conveyed to the chimney. A boiler of this kind evidently requires a large consumption of fuel, and has the further disadvantage of being very bulky. It is much used in the American engines.

65. *Tubular Boilers.*—Various other forms of boiler have been suggested, with a view to economise fuel, bulk, and weight. In 1774, Blakey had proposed to use *cylindrical tubes* for boilers, in order to obtain a larger heating surface in a smaller space; for it is found that the effective generation of steam depends more on the extent of surface exposed to the direct action of the furnace, than on the general bulk of the boiler. Several varieties of tubular boilers were contrived by Count Rumford and Arthur Woolf; these were, however, of complicated construction, and were necessarily weak from being made of cast iron. The following figures exhibit a form of boiler, which may be considered as a transition form from the tubular-flued already described; the smaller figure presents a transverse, the larger a horizontal and vertical section, of this apparatus. The flame and heated air pass into the large tube, which has half its circumference in contact with the water, while two

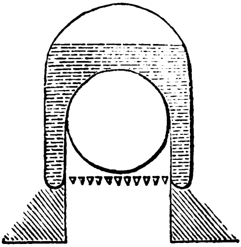

Fig. 33.

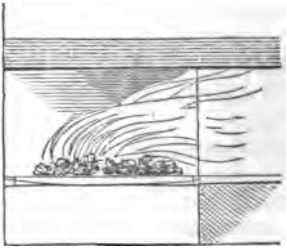

Fig. 34.

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vertical portions of the boiler, called 'water legs,' receive the heat on each side, as seen in the smaller figure. In this apparatus the heat is economised, being conveyed to the boiler without any expenditure of it upon the brickwork of the furnace. A further economy of heat has been effected by substituting, in room of one large tube, a great many smaller tubes of about six inches in diameter, as in the following figures:—

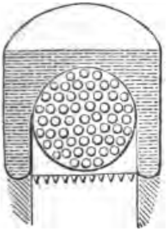

Fig. 35.

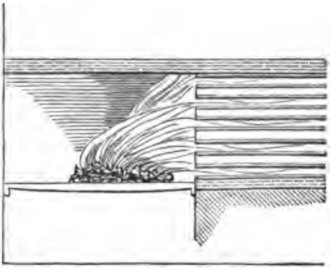

Fig. 36.

In this form of boiler, the flame and hot air, after traversing the tubes, circulate in the space beneath the boiler previously to their being conveyed to the chimney.

66. *General Remarks on Boilers.*—The following observations on the construction and economy of boilers, taken from Mr. Scott Russell's Treatise on the Steam Engine, published in the Encyclopedia Britannica, serve to show the difficulty of adjusting the several parts of this important piece of apparatus. "The conclusion to be drawn from all that has been attempted or achieved in boilers, is, we believe, the following:—That there exist certain limits prescribed by the constitution of fuel, the nature of metals, and the properties of water and steam, which cannot be exceeded without incurring evils that greatly overbalance the partial gain. The best boilers that have ever existed have been those in which a large number of principles have been applied, and so adjusted in relation to each other as to gain the

maximum, not of any one property, but of all the valuable properties, each in the degree of its individual importance. The first cost of the boiler must not be rendered too great, or that will neutralize the economy of using it; the space to which it is confined may be as small as possible; but, if that be produced by intricacy of construction, the loss may surpass the advantage. Then, again, if complex and confined, it may be impossible to cleanse or to repair the boiler; and therefore it must be remembered, that unless easy access can be gained to every part of a boiler, and of its flues, that boiler will soon become totally useless. Then, it is further demanded of a good practical boiler, that, if one part should be damaged or give way, the whole should be so constructed that the damage done to that part must not endanger the rest. An extensive heating surface is to be obtained for economy's sake; but that large surface must at the same time remain unimpaired to resist burning; a property to a certain extent inconsistent with extensive surface. The surface which is thus spread as widely as possible, so as to apply the fire to the water through every part of its mass minutely and in great subdivisions, if extended beyond a certain degree, will not have over it a body of water capable of conducting heat from it with the rapidity adequate to the rapid generation of steam, and to the preservation of the intensely heated metal from the destructive action of the fire. Then, again, it is desirable to have long and tortuous flues, to extricate as much heat as possible from the fuel and the products of combustion; but these, by their very length, may interfere with the draught of the chimney, so as to diminish the efficacy and vigour of the combustion of the fuel, and produce loss instead of gain. Thus it happens that the whole question of boilers is an exact and judicious combination and adjustment of parts, so as to obtain each of these many points in that degree which is most advantageous for every one of the other qualities, and of all of them together. The question is a practical one of no common difficulty." These are important remarks on a most important subject.

67. *Strength of Boilers.*—In determining the *material* of which steam boilers should be constructed, the first object to be considered is *safety.* It is, therefore, necessary to ascertain what *excess of strength* a boiler should possess in order to ensure safety. On this subject Tredgold observes: "It is clearly a matter of opinion, founded on the experience of past accidents, as to the degree of pressure required, and it has been almost universally allowed, that three times the pressure on the valve in the working state should be borne by the boiler without injury. This degree of excess of power seems to be fully sufficient for the ordinary *low-pressure boilers;* indeed, I should think twice the pressure a proper allowance; and, were it always provided, there would be little chance of accident, if the valves be properly constructed and attended to. It becomes insufficient in *high-pressure boilers,* because a common low-pressure boiler contains about ten times the volume of steam required for one stroke of the engine, consequently the time of twenty strokes must elapse before the density of the steam could accumulate to three times its working density, supposing the engine to be stopped, and the valve out of order; but if the boiler contains only as much steam as is required for one stroke, the force will be increased to three times in the time the engine would have made two strokes. This rapidity of the increase of force does not leave the necessary time to examine, nor even to open the valves in this extreme case, and the hazard must be greater in consequence. In all cases the time of accumulating power should not be shorter than it is in the common boiler. Besides, in working an engine where the excess of force increases so fast, the loss of steam would be considerable from any variation of the heat of the fire, even were the valve to act properly, and, therefore, there is a temptation to load the valve beyond its regular weight. To render the security on the stoppage of the engine equal in all cases, the *excess of strength should be inversely as the space allowed for steam.* It is still more important to consider the subject, in relation to the danger arising from

unequal action of the fire; and, for this, the excess of strength should be inversely as the contents of the boiler expressed in units of the power. Boilers may fail from strains produced by other causes besides the force of the steam, and these may be noticed to guard against the circumstances which produce them." Among these causes may be mentioned the explosion of inflammable gases in flues which are unscientifically constructed; and the formation of hydrogen gas within the boiler, owing to the water being in contact with a part of the boiler which is red hot. In reference to the latter circumstance, Tredgold adds that, although the presence of hydrogen in the boiler would not add to the risk of an explosion, it undoubtedly would render it more destructive if it should take place. The destructive effects of an accident which occurred at the Cyrfartha Iron Works were attributed to the inflaming of hydrogen accumulated within the boiler. The boiler was constructed of the old spherical form, twenty feet in diameter; the thickness of the plates, when new, was, top plates a full quarter of an inch, bottom plates half an inch; load on the safety valve 7 lbs. per circular inch. Many lives were lost by this explosion, and the boiler was thrown to a distance of 150 feet, to a place thirty feet above the level of its former seat. The upper plates were too weak.

68. *Materials of Boilers.*—The materials generally employed for the construction of boilers, are cast iron, wrought iron, and copper. 1. *Cast iron* boilers were employed by Smeaton with great success; they possess the advantage of cheapness, and, with careful management, will last for a long time; but, being brittle, they are liable to break from the effect of unequal expansion, or from increased pressure of steam. 2. *Wrought iron* boilers are much used in this country and in America. Being ductile, they are free from the objections to which the former kind is liable; but they are not free from the effects of incrustation arising from the deposition of foreign matters, which, being combined with the water, are liberated when the water is converted into steam. To obviate this difficulty, Mr. Gurney proposed to inject an

acid through the tubes, which should combine with the deposited matters, and carry them off. This plan was found to be difficult in practice, and it was afterwards proposed to remove the incrustation by mechanical means. 3. *Copper* boilers were substituted for those of iron, with the view of preventing the deposition of calcareous and other matters. It has been stated that these matters, instead of forming an incrustation on the copper, would merely be suspended in the water, and would be carried off by the *blowing process* (p. 41). This subject has been already alluded to at page 6. But Mr. Dinnen is decidedly of opinion, that it is unnecessary to prescribe any specifics for the prevention of deposit or of chemical action in copper boilers employed in marine engines; he states that the same effects occur in copper as in iron boilers, when submitted to the influence of a highly concentrated solution of saline and other matters, in a constantly boiling state, viz. deposition of salts and other deposits, and ultimate destruction of the boilers. But copper boilers possess certain advantages over those made of iron: copper is a better conductor of heat, and thus economises fuel and space; it is much more durable; it is more uniform in its durability; and it is valuable, as a commodity, when old. On the other hand, copper is much more expensive at the first outlay; and it is more flexible than iron at high temperatures.

69. *Deposits on the outside of Boilers.*—Mr. Dinnen has pointed out a serious evil which occurs in marine boilers, whether made of copper or of iron. This is the accumulation of soot, salt, &c., in the flues, the chemical action of which is very destructive to boilers. Water, he observes, whether cold or boiling, filters through numerous apertures insignificant in dimensions, and almost inseparable from the intricacy of the construction, and mixes with the soot, forming a combination which corrodes the material very rapidly. The heat of the boilers, when employed, evaporates the water, and leaves the salt, &c., in a concrete state; which, when cold, is again dissolved, and recommences its action

more formidably. In cleaning out the flues of a copper boiler, "the congeries of salt, soot, and water, was thrown out upon the iron plates of the engine room flooring, where it remained for nearly two days; when removed, and the plates well washed, a pretty and novel phenomenon was exhibited. The iron plates had precipitated the copper from the solution which covered them, exhibiting a *permanent metallic surface of copper*." The leaks from which the salt escaped were found to be so unimportant, that the usual measures to staunch them could not be attempted without the risk of increasing the evil. Mr. Dinnen is of opinion, that copper boilers undergo more injury than those of iron from these deposits. The remedy must be found in sweeping the flues as often as possible, and keeping the boilers perfectly dry when unemployed. As a last remedy he recommends the application of cement to the angles and fillets of the flues, so as to completely enclose the angle pieces, with their defects.*

70. *Feeding Apparatus of Boilers.*—The loss of water in the boiler by the expenditure of steam, should be supplied uninterruptedly, so as to prevent any considerable variations in the level and temperature of the water. Various contrivances have been adopted, in order to secure the attention of the engine man to this object. 1. In the early engines of Newcomen and Savery, the quantity of water in the boiler was regulated by the use of *two gauge cocks*. The nature of this apparatus may be seen in the atmospheric engine at page 27, and it is described in page 28. 2. In the early engines of Watt, a self-acting *steam whistle* was connected with the boiler. It consisted in a tube, one end of which was inserted into the boiler at the lowest level to which the water was to be allowed to fall, while the other end was conducted into the engine-house, where it terminated in a mouth-piece or whistle. When the water had fallen to this level in the boiler, the steam rushed through the tube, and

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* Dinnen on *Marine Boilers.* Appendix in Tredgold.

loudly admonished the attendant to shake off his slumber, or quit his repast, and to feed the boiler. 3. A third contrivance consisted in applying to the boiler a glass tube, bent at right angles at both ends, as represented at T T' in the adjoined figure; one of the ends entering the boiler above, the other below, the required level of the water. From a well-known law of liquids, it is evident, that the water will stand at the same level in the boiler and in the tube, and thus the attendant will be enabled to *see*, without taking any further trouble, when his services are required. 4. Another contrivance for indicating the periods of replenishing the boiler, is addressed to the *eye* of the attendant in the apparatus of the following figure. Let the water in the boiler be supposed to be at its proper level. A weight F may be so prepared as to be nicely balanced, when *half immersed in water*, by a counter weight, A, connected with it by a flexible string, passing steam-tight through the boiler, and working over a wheel W. When the water falls or rises in the boiler, the balance between the weights is destroyed: if the level of the water rise, the weight F rises also, and the weight A falls; if the level of the water fall, F falls with it, and A rises. By attaching a rod across the wheel, or fixing two pins to its circumference, which shall be in the horizontal position when the water is at its proper level, an index is at once obtained by mere inspection of the wheel. 5. But, after all, the engine man may happen *not to look*, and the consequence may be serious. Hence it is necessary, that the engine should be enabled to supply its own boiler, by what is called a *self-feeding apparatus.* A contrivance of this kind has been already described and illustrated at page 86. Other kinds of self-regulating feeders have been employed, on the same principle as that referred to.

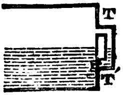

Fig. 37.

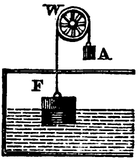

Fig. 38.

71. *On increasing the Evaporating Power of Boilers.*—A contrivance has recently been introduced by Mr. C. W. Williams, of Liverpool, for effecting a more rapid generation of steam, without increasing the size of the boiler, or requiring any additional fuel. The object of his discovery is to transmit the greatest possible amount of heat for the generation of steam, with a given quantity of fuel. He considers, that nine-tenths of the heat in marine and land engine boilers are immediately received from the furnace and flame-bed, and not from the heated gases, which might be made more available, to the same end, by an improved construction of boiler. His plan is, to insert a number of iron pins through the plates of the boiler, one end of them projecting into the flue, the other into the water in the boiler. These pins, exposed at one end to the heat in the flue, act as powerful conductors, through the boiler-plates, of the heat into the water. Hitherto, the question of the mere surface of plate exposed to the flues had been alone considered; and the only remedy for the defective generation of steam, was conceived to be an increase of that surface. The *conducting pins*, however, were found to absorb the heating gases in their progress along the plates of the boiler, and greatly to hasten the generation of steam. A pin of half an inch in diameter, projecting three inches into the flue, gave a heating surface of four and a-half inches; and by its conducting power and interior projection, *that half inch gave as much heat as nine half inches on the outer surface of the plate.* Air is a good conveyor, but a bad conductor, of heat; for it carries most of it up the chimney. The great object is, to arrest the heat in its progress, and give it out at the right place. The current of heat passing along the plates of the boiler, rendered them only transverse conductors; but the heated pins were *longitudinal conductors.* The proper length of these pins, to insure a continued conduction of heat, is found to be about four inches; a pin of this length having been observed to be so little affected by the test of experiment, that the smallest mark

which it originally bore was distinctly visible. Mr. Williams lately illustrated his invention, before the Liverpool Polytechnic Society, by means of three evaporating pans, one of them having pins projecting into the boiler, and also into the flues, which he called *double conductors;* the second, with pins projecting into the flue only, called single conductors; and the third, a plain boiler, on the usual plan, without any such conductor. The first was found the most powerful in producing speedy evaporation, though the second was scarcely inferior; the third, or plain boiler, was greatly behind both the former in evaporating power. A gas lamp was affixed at one end of the double conducting pan, containing 22 lbs. of water, and the evaporation appeared to be rapid. With 30 feet of gas the evaporation was as follows:—

	Evaporation.	Waste Heat.
Common pan . .	4 lbs. 14 oz. .	406
Single conductors .	7 .. 13 .. .	320
Double conductors .	8 .. 5 .. .	284

It will be observed, that the quantity of water evaporated is in an inverse ratio to the waste heat of the chimney. Mr. Durance, engineer of the Liverpool and Manchester Railway, stated, that he had tried the conducting pins in the boiler of one of their stationary engines with great success. He had only 105 pins driven into the boiler, and the steam, which could not before be kept up, was now abundant.—*Railway Magazine*, Oct. 30, 1841.

72. *Self-Regulating Furnace.*—It is not compatible with the limits of a treatise of this kind, to enter into the numerous details connected with the construction of the various forms of furnace, grate, and ash-pit. But as the furnace, like the boiler, must be incessantly *fed;* and as the method of feeding it by the hand is liable to the objection of admitting cold air to the fuel, or may lead to the result, as in the case of the boiler, of *its not being fed at all*, it is interesting to know what has been done for the purpose of constructing a *self-regulating furnace.* A contrivance of this kind has

been invented by Mr. William Brunton, of Birmingham, and it is the only one which has succeeded in practice; its advantages are set forth in his patent:—"First; I put the coal upon the grate by small quantities, and, at very short intervals, say every two or three seconds.—Secondly; I so dispose of the coals upon the grate, that the smoke evolved must pass over that part of the grate upon which the coal is in full combustion, and is thereby consumed.—Thirdly; As the introduction of coal is uniform in short spaces of time, the introduction of air is also uniform, and requires no attention from the fireman.

"As it respects economy:—First; The coal is put upon the fire by an apparatus driven by the engine, and so contrived, that the quantity of coal is proportioned to the quantity of work which the engine is performing; and the quantity of air admitted to consume the smoke, is regulated in the same manner.—Secondly; The fire-door is never opened, excepting to clean the fire; the boiler, of course, is not exposed to that continual irregularity of temperature which is unavoidable in the common furnace, and which is found exceedingly injurious to boilers.—Thirdly; The only attention required, is to fill the coal-receiver every two or three hours, and clean the fire when necessary.—Fourthly; The coal is more completely consumed than by the common furnace, as all the effect of what is termed stirring up the fire (by which no inconsiderable quantity of coal is passed into the ash-pit) is attained without moving the coal upon the grate."

RECAPITULATION.

53. What are the essential parts of a *high-pressure* engine? What are those of a *low-pressure* engine? By what other terms are these engines respectively designated?—

54. What is meant by *combustion?* How is the amount of heat, emitted by the combustion of any particular kind of fuel, determined? What is the average heat for the effective combustion of fuel? Enumerate the circumstances under which the due temperature for the combustion of fuel may be maintained.—55. What quantity of *oxygen* is required for the effective combustion of the different kinds of coal? What quantity of oxygen exists in a given quantity of atmospheric air? What quantity of atmospheric *air* is required to yield one pound of oxygen? How much air and smoke are required for the conversion of one cubic foot of water into steam?—56. How may the elasticity of high-pressure steam be ascertained? What is meant by steam exerting a pressure equal to that of *one pound on the square inch?* How may the pressure of steam be estimated by reference to that of the atmosphere? What is meant by *steam of two atmospheres?* Is there any other way of understanding this expression?—57. Explain the construction of the lever safety valve; and of a spring valve. How should the magnitude of the safety valve be determined?—58. What is the object of the fusible metal plug? What are the objections to its use? Why are *alloys* better adapted to the purpose? What is the true value of the fusible plug, as a precautionary means?—59. Explain the construction, and use, of the mercurial steam gauge. How is the amount of the pressure of steam indicated by this instrument? Upon what principle is the thermometer gauge employed?—60. What are the requisites in a boiler for the effective production of steam? What extent of surface is required in a boiler to convert a cubic foot of water into steam in an hour? What is the estimated proportion of the bottom surface of a boiler for a given effect?—61. What space for steam is usually allowed in a boiler? Under what circumstances does the space vary? What space for water is usually allowed? By what circumstance should the admission of water into a boiler be regulated?—62. What is the objection to the *spherical* form of boiler? What modifica-

tions of this form were introduced?—63. Explain the form of the *waggon boiler*. Describe the apparatus by which it is supplied with water.—64. Describe the variety of cylinder boiler, in which the furnace is placed *inside* the boiler. Describe the apparatus, in which the furnace is *outside* the boiler.—65. Explain the construction and economy of a *tubular* boiler.—67. What *excess of strength* is required in a low-pressure, and in a high-pressure, boiler, for the purpose of safety? Enumerate some of the sources of danger to which a boiler is exposed.—68. What are the advantages of copper and wrought iron boilers over those made of cast iron? What are the comparative merits of copper and of wrought iron boilers?—69. Explain the nature of the matters deposited on the outside of marine boilers.—70. Describe the various contrivances which have been adopted for regulating the supply of water to the boiler.—71. Explain the method adopted by Mr. Williams for increasing the evaporating power of boilers. By what experiment was his method illustrated?—72. What are the advantages of Brunton's self-regulating furnace.

CHAPTER VII.

OF THE SEVERAL PARTS OF THE MODERN STEAM ENGINE *(continued)*.

73. *General Remarks.*—In the preceding chapter, the attention of the reader has been directed to the apparatus constituting the boiler and its appendages. We proceed to the further consideration of the several parts of the modern engine, according to the following arrangement:—

1. *Of Cylinders.*
2. *Of Pistons.*
    1. *Packed piston.*
    2. *Metallic piston.*
3. *Of Valves.*
    1. *Reciprocating.*
        1. *Rising.*
            1. *Flat valves.*
            2. *Conical valves.*
            3. *Spherical valves.*
        2. *Sliding.*
            1. *Murray's slide.*
            2. *Murdock's slide.*
            3. *Seaward's slides.*
    2. *Rotary.*
        1. *On an axis: throttle valves.*
        2. *Conical valves, or cocks.*
            1. *Common cock.*
            2. *Four-passaged cock.*
4. *Of the Eccentric.*
5. *Of the Barometer Gauge.*
6. *Of the Indicator.*

OF CYLINDERS.

74. *Morland's Calculations.*—It has been stated (page22), that some calculations were made by Sir Samuel Morland, as early as 1683, on the dimensions of cylinders adapted for raising, by steam, a certain quantity of water to a given height in a fixed time. On this subject, he observes:—"Water being converted into vapour by the force of fire, these vapours shortly require a greater space (about 2000 times) than the water before occupied, and, sooner than be constantly confined, would split a piece of cannon. But being duly regulated according to the rules of statics, and by science reduced to measure, weight, and balance, then they bear their load peaceably (like good horses), and thus become of great use to mankind, particularly for raising water, according to the following table, which shows the number of pounds that may be raised 1800 times per hour, to a height of six inches, by cylinders half filled with water, as well as the different diameters and depths of the said cylinders." These statements are remarkable for the period in which they were made; for they are not far from the truth. The following is the table:—

Cylinders.		Weight of the load to be raised, in pounds.
Diameter in feet.	Depth in feet.	
1	2	15
2	4	120
3	6	405
4	8	960
5	10	1875
6	12	3240

75. *Proportions of Cylinders.*—The proportions of a cylinder bear an obvious relation to the *extent of cooling surface* to which the steam is exposed within it during the

stroke of the piston; and to the *length of the stroke* itself. The effect of a *cooling surface*, is to diminish the force of the steam. In Newcomen's engine, a naked cylinder was employed, and considerable loss of force was entailed by its exposure to the atmosphere. In Watt's engine, a remedy was proposed against this loss, by enclosing the cylinder in an outer case, called a *jacket*, the intervening space being filled with steam.* As the power of an engine is greatest when the force of a given quantity of steam is at its *maximum* effect, and as the cooling surface should be of as small extent as possible, it follows, that in determining the proportions of a cylinder, the object is to find the *minimum* extent of surface which will confine a given quantity of steam during its action. Upon this subject, Tredgold says, that "when *the length of the stroke is twice the diameter of the cylinder*, a given quantity of steam is bounded by the least possible quantity of surface during its action in the cylinder; hence I conclude it is the best proportion for the cylinder of a steam engine, except when the space for the engine limits the length of the stroke; and the same conclusion applies to both atmospheric and steam pressure engines." In other words, a cylinder is of the best proportion when *its length is twice its diameter*. This rule has, however, not been strictly attended to in practice. The proportions observed in Watt's engines, in cases in which the stroke has not been limited, have varied from 1¾ to nearly 3 to 1, the usual proportion being about 2·7 to 1. Similar deviations from the above rule have occurred in the engines of other manufacturers. It appears to have been their aim to produce a uniform velocity in all engines.

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* Tredgold observes, that the loss of fuel by this mode is the same as with a naked cylinder, and that there is clearly no advantage in preserving the force of the steam by adding this case, unless it be supplied with steam by a separate pipe: the circulation of the steam between the cylinder and the jacket, exposes it to the cooling effect of the atmosphere, and thus reduces its elastic force before it enters the cylinder to exert its power. The loss in low-pressure engines is estimated at 1-100th, whereas, in high-pressure engines, working at 300°, the loss by a naked cylinder is only about 1-65th part of the force of the steam. He adds, that the best mode of preventing loss, is to put a case with an air-tight cavity between it and the cylinder, instead of filling this case with steam; the advantages would be, economy of fuel, and reduced temperature of the engine room.

OF PISTONS.

76. *Conditions of the Piston and Piston-Rod.*—1. The simplest idea of a *piston* may be derived from the figure at page 13; it is there represented as a circular disc or diaphragm, capable of moving up and down within a syringe or tube, which is thus divided into two compartments. The general application of such an apparatus to the purposes of a steam engine, is briefly stated at page 27. From what has been there said, it will be evident, that in the construction of a piston, two conditions are indispensable: *first*, it must be perfectly steam-tight; and, *secondly*, it must be as free from friction against the tube as is compatible with the first requirement. To secure these conditions, it was, at an early period, found necessary to surround the piston with some elastic material, which should render it tight, and yet admit of its free reciprocating action; this process is called *packing* the piston. 2. The connexion of the *rod* with the piston, in the atmospheric engine, is firmly secured by several smaller rods, which branch from the stem, and are fastened to the upper surface of the piston, as represented in the annexed figure. This mode of connexion, though unobjectionable in an open cylinder, is obviously inadmissible in a close cylinder, in which the upper surface of the piston is brought into immediate contact with the top of the cylinder at each stroke of the engine. 3. Again; the *stem* itself of the piston-rod, working in an open cylinder,

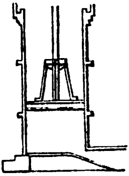
Fig. 39.

required no determinate shape, no smoothness of surface; but, in passing up and down through an aperture formed in the cover of a steam-tight cylinder, it was necessary that it should be of a round shape, of uniform thickness, and of polished smoothness. The aperture in the cylinder through which the rod passes, is provided with an apparatus termed the piston-rod collar, or *stuffing-box;* it is represented at B in the following figure. The contrivance for rendering this aperture steam-tight depends, like that adopted for packing the piston, on the employment of some elastic substance, as leather, hemp, cotton, cork, or metal. In fig. 40, the cylinder is perforated by a hole of sufficient dimensions to admit of the easy passage of the rod. A box is cast round this hole, and its inner surface lined with a collar or packing of hemp, which is saturated with oil or melted tallow; the position of the hempen collar is denoted by the two dark portions of the figure. A ring of metal is placed above the packing, and pressed tightly down with screws, so as to force the elastic material into every crevice. The lubricating matters are poured in from time to time at the upper concavity of their latter ring. Stuffing-boxes of this kind are employed in all cases in which a moveable rod is introduced into a steam-tight cavity, as in the valve boxes of cylinders, in boilers, &c.

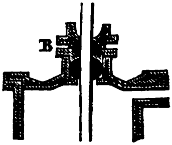

Fig. 40.

77. *Packed Piston.*—The earliest and rudest form of piston consisted in a circular block of wood. In 1713, the idea of applying leather to the circumference of the piston occurred to Beighton: he found, that "a bridle rein, or even a soft thick piece of rope or match, going round, would make the piston air and water-tight." But, the heat of steam being injurious to this material, a packing of hemp was employed by Watt. The following figure represents a *hemp-packed piston;* it is most commonly employed in steam engines, and is of the following construction. The lower

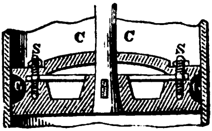

Fig. 41.

part of the piston consists of a circular metallic plate, the diameter of which is somewhat less than that of the cylinder C C; this plate soon begins to curve inward, so as to form a circular channel or groove for the packing. The upper part of the piston consists of another plate, which also curves inward, and completes the groove. Within this groove, and between the projecting rims of the two plates, bands of unspun long hemp, or soft rope, termed *gasket*, are wound round the piston; the position of the gasket is seen at G G, in the vertical section above. The packing is tightened by screws S S, which pass from the upper to the lower plate of the piston; and this tightening, aided by the semicircular form of the groove, presses the elastic material against the inner surface of the cylinder. When the packing wears, so as to become too small, the screws are tightened, in order to press it outward; and, when this plan fails, the packing must be renewed. The friction of hemp packing on iron, is stated by Tredgold to be about one-sixth of the pressure on the piston; hence the thickness of the packing should be one one-sixth of the diameter; the rule is, however, not observed in practice. The *rod* of the piston is of a somewhat conical form at its lower part; it is fixed in a hole made through the piston, and firmly secured by means of a screw nut or wedge.

78. *Woolf's Piston.*—The inconvenience of removing the top of the cylinder, in order to tighten the screws when the packing became worn, suggested to Woolf the following contrivance, by means of which the screws might be tightened without taking off the top of the cylinder, except when the packing required to be renewed. He adapted to the head of each of the screws a small toothed wheel or pinion, and placed on the surface of the piston a large central toothed wheel, which revolved on the piston-rod as an axis, and

worked in gear with all the screw wheels, so as to be capable of driving them all at once. By this apparatus, all the screws may be turned, by merely turning one of them. This one is furnished with a square head, and turned by a key through a hole in the cylinder; the hole is secured by a metallic plate or cover, which is fastened down by screws, and may be readily removed as occasion may require. This apparatus has been further simplified, but upon the same principle.

79. *Metallic Pistons.*—In describing Cartwright's engine, it was observed (page 70), that the novelty in his machinery consisted in the substitution of a *metallic* for a packed piston. An obvious advantage of this contrivance is a diminution of friction; the average friction of brass upon iron being one-eighth of the pressure upon the piston. The following figures represent a vertical, and a transverse, section of Cartwright's piston; on comparing them with each other, it will be seen, that the part occupied by the gasket in the packed piston, is here occupied by metallic rings. In the lower figure, or transverse section, the outermost ring represents the cylinder. Two rings of brass, each divided into three segments, *a*, *a*, *a*, constitute the outermost portion of the piston; these rings being placed one over the other, only one of them can be seen in the transverse section, but both may be seen, designated by the same letters, in the vertical section, or upper figure. Two other rings of brass, similarly divided into segments, are applied immediately upon the inner surface of the preceding rings, the points of their division being alternate with

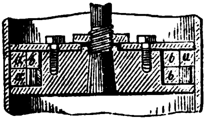

Fig. 42.

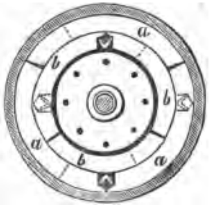

Fig. 43.

those of the outer pair; these segments are marked by the letters *b*, *b*, *b*, in both figures; the dotted lines denote the points of division of the lower rings. The segments of these series of rings are pressed outward by steel springs, in the form of the letter V; the springs which press upon the outer series rest upon the inner series, while those which press upon the inner series, rest upon the central portion of the piston; both are represented in the lower figure, the dotted springs being those of the lower series of segments. It is evident, that with such comparatively inflexible materials, it is indispensable that the cylinder be accurately bored throughout its entire length. An improved construction of the metallic piston was introduced by Mr. Barton; and various other modes of applying metal to render pistons steam-tight have been adopted; the general principle of these may, however, be sufficiently understood by the above description.

OF VALVES.

80. *General Remarks on Valves.*—A valve is a contrivance for opening or closing a passage for steam. The valves employed in steam engines vary in their form, and in their mode of action; they have been arranged at page 101, with reference to the latter principle. Valves which have an alternate motion, upwards and downwards, are called *reciprocating* valves; while those which revolve upon an axis, are termed *rotary* valves. Reciprocating valves may be opened and closed in two ways: they may *rise* out of their seat or socket, and fall into it again; or they may *slide* over the steam-passage, forward and backward, alternately. Rotary valves include what are more generally termed *cocks;* these are usually constructed like the common stopcock, excepting that they command more passages than one at the same time. The efficiency of a valve consists in its capability of being opened with as little force, and as little delay, as the circumstance of the case may require. Valves become

more difficult of management in proportion to the greater area of the aperture to which they are adapted; according to Tredgold, the area of the passage, when open, should be rather more than equivalent to that of the narrowest part of the pipe. The principal forms of valve will be, first, described; and, afterwards, the mechanism by which they are worked.

81. *Clack Valves.*—The principal valves employed in the construction of steam engines are made of metal, in consequence of the heat to which they are exposed; and they are fitted by grinding to their seats. Valves made of leather, like the common clack valve of a pump, can only be employed in those parts of an engine in which the temperature is low. The *clack valve* consists of a flat plate of leather a little larger than the aperture which it is intended to close; it is strengthened by a metallic plate on its upper, and another on its lower, surface, the upper plate being larger, the lower one smaller, than the aperture; it should open at an angle of 30°, so as to admit of a free passage, equal to its aperture. 1. A *single clack valve* of this kind will be observed in the plate of the Single Acting Engine, page 40, at M, where the condenser communicates with the air-pump; this is called the *foot valve.* Another may be seen in the same plate, at K, where the barrel of the air-pump communicates with the hot cistern. In these cases, the valve is suspended by a hinge joint to the upper part of the aperture which it guards, and it falls against an inclined seat at an angle of just sufficient magnitude to enable the valve to close the aperture by its own weight. 2. A *double clack valve* consists of two semicircular valves, which are commonly employed for pump-buckets, and they are then made as above described; they may be seen in the barrel of the large pump on the extreme right of the plate, at page 40. In steam engines, these double clacks are usually made of metal, and they are made to open at the angle above described. In the following figure is represented a portion of the barrel C of an air-pump, with its piston. The semi-

circular valves are exhibited as raised, at *v v*, to admit of the passage of air and water upwards through the apertures *a a*. This machinery is shown in the plate, page 40, at N; and, again, at the plate, page 60, at A; in these cases, however, the valves are represented as closed. The reader is referred to these plates, and to the accompanying description, in order that he may understand the precise action of this kind of valve.

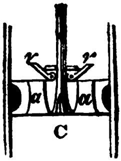

Fig. 44.

82. *Conical Valves.*—The *conical valve* consists of a flat circular plate of metal, having its rim bevelled and ground so as to fit in a conical seat or nozzle. Three of these valves may be seen connected with the cylinder of Watt's single engine, at page 40; and four of them, in the double engine at page 60; some of these are represented as open, others as closed. The annexed figure exhibits an enlarged view of one of Watt's steam boxes, containing a conical valve *v v*, seated, like a plug, within the nozzle *n;* the steam, which enters from the boiler by the tube S, is thus prevented from entering the cylinder. These valves and nozzles are sometimes made of brass; but are better when made of gun-metal. "The diameter of the valve box should be to the greater diameter of the valve as 3 to 2; and the valve should not rise less than one-fourth of its greatest diameter when quite open; but both these proportions must be increased if the valve be out of the centre of the box. The best angle for the valve to fit in its seat is 45°, for the pressure is balanced by the reaction of the sides. With less taper, the valve has a tendency to set fast; with greater, it occupies more space. When the conical valve exceeds five or six inches in diameter, it requires great power to open it against the pressure of the steam, and is therefore inconvenient."—

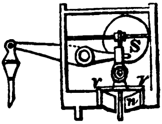

Fig. 45.

(Tredgold.) These valves are also called *spindle valves*, from their being furnished with a round spindle or axis which passes perpendicularly through their centre, projects on either side, and plays in holes above and below the valve, for the purpose of securing its regular fall into its seat. The spindle is represented in the above figure. These valves are also called *puppet clacks*, and *button valves.*

83. *Spherical Valve.*—From the conical, the transition is easy to the *spherical* valve. In this form of valve, the seat or nozzle represents a portion of a sphere; the valve itself may be also a portion of a sphere, or an entire sphere. A valve of this kind is represented in the adjoined cut; it has been recommended, as a safety valve, to prevent the danger of adhering in the boilers of steam vessels. The valve *v* is of a hemispherical form, having its convex surface directed downward, with a weight W depending from it into the boiler B. It was supposed, that such a valve would move in its seat, so as to accommodate itself to the rocking of the vessel, and thus remain steam-tight, without danger of being fixed. This form of valve is termed a *cup valve.*

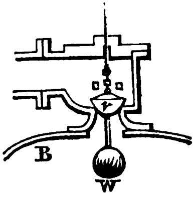

Fig. 46.

84. *Murray's Slide.*—Sliding valves are those which do not rise from, and fall into, their seat, like the three preceding kinds, but slide on and off their apertures; hence, they are commonly called *slides.* The advantage of a slide will be readily seen by comparing its mode of action with that of the valves already described. In Watt's double engine, the cylinder is worked by four conical valves, which govern four passages, and require four levers for the performance of their reciprocating motions. In modern engines, the steam passages are opened and closed by the action of a single slide. There are various kinds of slide employed in water works, gas works, and steam engines, but the principle is the same in all. The following figures represent

the slide applied by Murray, in 1799, to the steam engine. In fig. 47, the steam passages are represented as all terminating in a steam-tight case A B, which is fixed to the left side of the cylinder. The steam enters from the boiler at S, and passes through G, in the direction of the arrow, to the top of the cylinder; while the steam from the bottom of the cylinder passes through H, in the direction of the arrows, into the condenser at C. In the following figure, the condition of these passages is exactly reversed; and this is effected by the small reciprocating motion of a slide. In each figure, E D represents a rod, which moves steam-tight, through a stuffing-box, in the steam case A B; the rod is fastened at its upper extremity to the slide F. In fig. 47, *the slide is down*, and the steam rushes to the top, and from the bottom, of the cylinder, as above described. In fig. 48, *the slide is up*, and the steam rushes through H, in the direction of the arrow, to the bottom of the cylinder, while the steam at the top of the cylinder rushes at the same time through G, in the direction of the arrow, into the condenser. By this simple and admirable contrivance, *the office of four valves is performed by means of a single slide.* The friction of the sliding surfaces is obviously considerable, owing to the great pressure of the

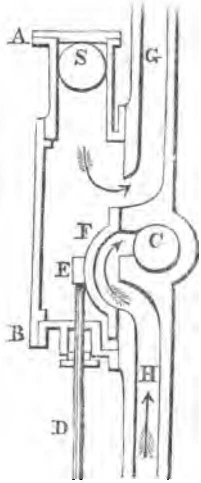

Fig. 47.

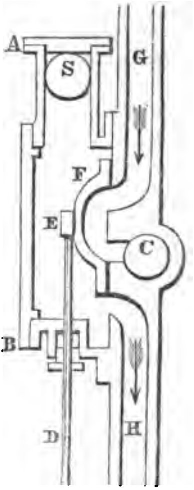

Fig. 48.

steam from the boiler on the convex surface of the slide, and the little counter pressure of the steam, as it passes to the condenser, on the concave surface. To obviate this difficulty, and secure the surfaces from injury by wear, it is necessary, first, to make the sliding surfaces as large as may be convenient, and, secondly, to construct them of durable material. For steam vessels, gun metal is employed for this purpose; in other cases, in which salt water is not used, the sliding parts may be made of hardened steel.

85. *Murdock's Slide.*—In the preceding figures, it has been seen, that the steam, in its course to the cylinder, is conveyed through passages H and I, of great length; hence, there is a *waste of steam.* This objection would be removed, if the inlets to the cylinder were situated close to the steam tube. With this view, an improved form of slide, by which the waste of steam is prevented, was introduced by Murdock, and has been applied to Watt's engines, and to the more recent steam vessels of Maudsley. A simple idea of this apparatus may be derived from the two following figures, in which the cylinder and the slide are shown, separately. Fig. 49, represents the cylinder, with its steam-tight case AB, and the aperture C for admitting steam from the boiler; by this contrivance, the strong steam rushes into the top and bottom of the cylinder, without passing through long passages, as in the preceding apparatus. Fig. 50, represents the *slide*, the upper and lower parts of which are of a semicylindrical form; to each of these parts a flat plate is fixed, so that a transverse section of the slide at its upper or lower part, would present a figure resembling the letter D; hence, this slide is termed the D-*slide*

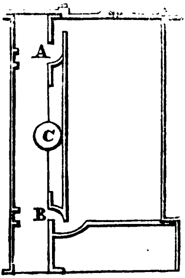

Fig. 49.

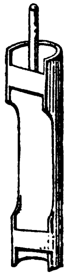

Fig. 50.

valve. Let the slide now be supposed to be placed in the steam case, with its flat plates towards the cylinder; it is obvious, that by sliding up and down, the flat plates will open or close the passages leading into the cylinder.

In the following figure, the slide is shown *in situ*. A B is the steam case; *a b* represents a vertical section of the slide, with a channel *p* passing longitudinally through it; R is the rod, which passes through a stuffing-box A, and moves the slide up and down. S is the mouth of the steam tube, leading from the boiler; C is the pipe leading to the condenser; *h h* is a hollow space produced by the cavity of the slide, communicating above and below with the cylinder; and always filled with strong steam. In the figure, the *slide is up;* the steam, therefore, rushes through *t* to the top of the cylinder, and is cut off from the bottom; the steam from the bottom of the cylinder rushes at the same time through *d*, up the channel *p*, and escapes into the condenser by C. When the *slide is down*, the condition of the passages is reversed: steam will rush into the lower part of the cylinder through *d*, which will now communicate with the space *h h;* while the steam at the upper part of the cylinder will rush through *t*, which will then be in close communication with C, and escape to the condenser. In this apparatus, the pressure of

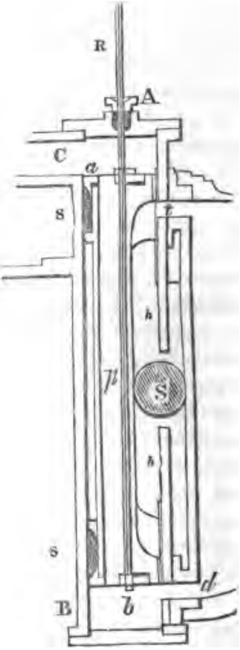

Fig. 51.

the steam in the space *h h* has a tendency to force the slide backward, and thus impair the contiguity of the sliding surfaces; this effect is guarded against by the packing s s at the back of the slide. In engines with a long stroke, two separate slides are used, the one for the upper, the other for the lower, part of the cylinder; but they are both worked by one rod.

86. *Seaward's Slides.*—In 1835, a patent was obtained by Mr. Samuel Seaward, for an improved form of slides, which are capable of being so adjusted as to cut off the steam at any part of the stroke, and thus to work the steam *expansively*. Several of the Government, Hull, Ramsgate, and Gravesend packets are fitted with these slides. A section of a cylinder provided with Seaward's slides is represented in the following figure. 1. *On the left of the cylinder*, steam is supplied from the boiler by the tube A, which communicates with the upper part of the cylinder by the passage S, and with the lower part by the passage S'. These passages are formed through metallic nozzles cast upon the side of the cylinder; on each of the nozzles is applied a plate of metal, having a smooth surface presented towards the steam tube. Upon these surfaces, two flat slide valves B B', also with smooth surfaces, are caused to move, either both together, or separately; the slides are attached freely by knuckle-joints to short rods E E', which move upward and downward through stuffing-boxes. The action of these slides is such, that, while they are continually pressed closely upon the surfaces on which they slide by the force of the steam, they are capable of being lifted off these surfaces by any undue pressure from within the cylinder, arising from accumulation of water within it. 2. *On the*

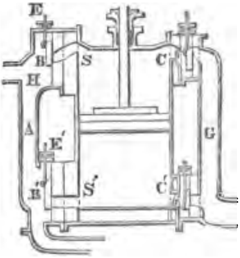

Fig. 52.

right of the cylinder, two similar slide valves, *b b'*, regulate the discharge of steam from the cylinder through the passages C C', which communicate with a tube G, leading to the condenser. In small double acting engines, these passages are sometimes brought sufficiently close to each other, to be capable of being regulated by a single slide, moving upon both apertures. These four slides may be moved separately; the steam may thus be cut off by the slide B, at any portion of the stroke of the piston, and thus worked *expansively*, without interfering with the motions of the other slides; yet they may all be worked by one apparatus, that of the *eccentric*, which will be presently described. From this account, it appears that these slides combine several advantages: they are perfectly steam-tight, with the least possible friction; they require no packing; any one of them may be worked independently of the others; and they are so constructed, that any water which may be accumulated in the cylinder, is driven through them into the steam tube, and carried back to the boiler.

87. *Throttle Valve.*—The valves and slides already described have a reciprocating motion. There are other kinds of valve, which have a *rotary* motion, or revolve on an axis. One of these is the *throttle valve;* its action is that of the floodgate of a mill; its purpose is to regulate the power of a steam engine, by increasing or diminishing the area of the steam tube, and thus to increase or diminish the amount of steam supplied to the cylinder. A valve of this kind is represented in fig. 21, page 59. It consists of a circular plate of metal *v*, fixed on an axis within the steam tube, and it is turned in either direction by a series of levers, *p*, so as to be capable of obstructing, wholly or partially, the passage of the steam; if turned edgewise, it permits the steam to pass, as in the figure referred to; but, if turned transversely, it forms a diaphragm across the tube, and prevents the passage of the steam. This kind of valve is very useful in cases in which perfect tightness is not indispensable. Tredgold observes, that an axis valve of this kind has much advantage

over a valve of any other form for a circular pipe, because it contracts the aperture without being difficult to move, or presenting more than the necessary obstruction; but it is by no means an economical mode of varying the power of the steam engine. The throttle valve was connected with the governor in the engine of Watt.

88. *Conical Valves or Cocks.*—The use of a common *cock*, in opening and closing a pipe, is familiar to every one. The simplest form of this kind of valve, or *single cock*, consists in a plug of a nearly cylindrical shape, inserted into a hole of corresponding form and dimensions in a tube; the plug is perforated by a large hole, as in fig. 53, and is turned by a handle outside the tube. It is obvious, that when the perforation of the plug is in the same direction as the cavity of the tube, as in fig. 54, the steam is permitted to pass on through the cock; and that, when the cock is turned, so as to present the perforation of the plug at right angles to the axis of the tube, as in fig. 55, the steam is entirely cut off. In the single cock, the plug should not deviate much from the cylindrical form; the usual reduction of its diameter is about one-sixth of the length.

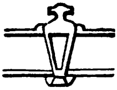

Fig. 53.

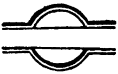

Fig. 54.

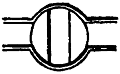

Fig. 55.

89. *Four-passaged Cock.*—A contrivance, founded on the principle of the common cock, has been adapted for putting *four passages* in communication with each other, alternately by pairs. This is termed the *four-passaged cock;* it has been figured and described in Leupold's engine, page 31, in which it forms communications between the boiler, two cylinders, and the external air. By means of the following figures, it will be seen, that communications may be established, by an apparatus of this kind, alternately from the

boiler and condenser, with the top and the bottom of a cylinder; and that these communications are effected by means of two passages, instead of four. In fig. 56, a circular metallic plate is represented, traversed by two curved passages, the one communicating with the steam tube S and the top of the cylinder by A, the other with the tube E leading to the condenser and the bottom of the cylinder by B; the handle which turns the cock is seen at H; the dotted curve shows the direction in which it is to be turned. In fig. 57,

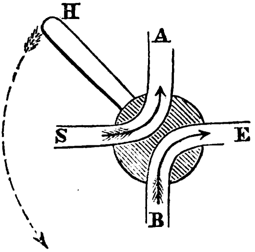

Fig. 56.

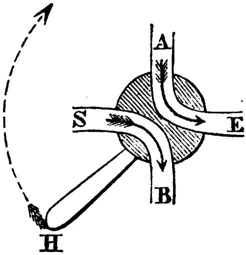

Fig. 57.

the handle has been pushed down in this direction, and the communications are reversed. The same letters denote the same passages as in the preceding figure; it follows, that the steam tube S now communicates with the bottom of the cylinder by B, while the top of the cylinder communicates through A with the condenser by E. On the subject of the four-passaged cock, Tredgold observes, that "the simplicity of its action in some degree compensates for its friction, but there is the disadvantage of part of the steam being lost in the pipes at each stroke. Its form should be nearly cylindrical, otherwise its friction and tendency to wear unequally will be increased. When it is ground to fit truly, the pressure of the steam tends to keep the surfaces in contact, and to wear the cavity into an elliptical shape; hence it is soon necessary to grind it to fit again." Instead of the four-passaged cock, two *double-passaged* cocks may be employed. The construction of this instrument may be readily conceived by referring to the preceding figures: if one of the passages be obliterated, the four-passaged becomes a double-passaged cock.

In engines which are worked on the *expansive* principle, some alterations must be made in the dimensions of the apertures of the four-passaged cock, in order to admit of the steam being cut off at any portion of the stroke. Accordingly, if, in one of the passages, the aperture leading to the cylinder be made larger than the other; if, in the other passage, the aperture leading to the condenser be made larger than the other; and, if the cock be so worked that the steam shall always pass to the cylinder by the former, and to the condenser by the latter, of these enlarged apertures; the cock may then be worked twice, instead of once only, so as to cut off the steam at the first movement, and leave the passage to the condenser open till the second. The expansive working of steam may, however, be more conveniently effected by means of two double-passaged cocks.

MECHANISM OF THE VALVES.

90. *Of the Eccentric.*—The mechanism by which the valves were worked in the early conditions of the steam engine, has been noticed, at pp. 30, 44, and 60. In these cases, the valves are opened and closed by the *reciprocating* motion of some part of the engine, as the *plug-frame*, which, rising and falling with the alternate motions of the piston, offers an easy mechanism for working the valves in pumping engines which have no rotatory motion. Mr. Scott Russell states, that he has seen this method adopted with advantage even in marine engines; he adds, that it is effective, in so far as it at once opens the passages to their fullest extent,

and so allows full effect to the entering steam, and full clearance to that escaping. Various kinds of mechanism have been more recently adopted for this purpose; but the apparatus most commonly in use in modern double acting engines, is that of the *eccentric;* and the action of this machinery depends on the *revolving* motion of some part of the engine, as the fly-wheel. This construction, and mode of action of the eccentric, may be understood by means of the following figure. A section of the shaft of the fly-wheel is shown at N; this is made to revolve by means of the crank of the engine. On this shaft or axis is fixed a wheel *k*, which revolves with it, but its motion is *eccentric* to it—that is, the centre *o* of the wheel does not coincide with the centre of the shaft, as is evident from mere inspection of the figure; and, hence, the centre *o* of the wheel moves round the axis of the shaft. The distance of the centre of the wheel from that of the shaft constitutes the amount of eccentricity, and this amount is equal to one half of the range of motion of the valves which are to be worked by this mechanism. The eccentric is encircled by a ring of metal *m*, which admits of the wheel revolving within it; to this outer ring is attached the arm *i*, which works upon a centre, and which, by means of a series of other arms or levers *h*, is connected with the opening and closing of the valves. The sum of this action consists in the conversion of

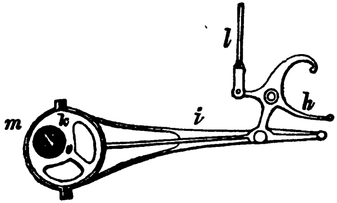

Fig. 58.

the rotatory motion of the fly-wheel shaft, into an alternate vertical motion of the valve-rod *l*. The advantage of an eccentric wheel is found in its smooth and unintermitting motion, producing the required changes without the perpetual recurrence of a stroke. In large engines, the pressure of the eccentric upon the shaft, is balanced by a weight.

91. *Condenser Gauge.* — There are two circumstances which determine the effective motions of the piston: one of these is the direct pressure of the steam from the boiler; the other is the resistance of the steam in the condenser. It is important to be enabled to ascertain the relative condition of these two antagonising agents. The pressure of the steam from the boiler is denoted by the steam gauge, already described (p. 81). But a certain quantity of uncondensed vapour, arising from the hot water in the condenser, resists the action of the piston, previously to its being withdrawn by the air-pump. The force of this vapour is ascertained by the *condenser gauge*, an instrument which is represented in the annexed figure. It consists of a glass tube A B, upwards of thirty inches in length, and open at both ends, the upper end communicating with the condenser C, the lower end being immersed in a cistern of mercury D. The weight of the atmosphere pressing on the surface of the mercury in the cistern, forces this liquid up the tube; the length of the column thus supported in the tube indicates the difference between the pressure of the atmosphere, and that of the vapour in the condenser. On comparing this column of mercury with that of the common barometer, we are enabled to ascertain the force of the vapour in the condenser, every two inches of difference in the columns being equivalent to a force of nearly one pound on the square inch (see p. 9). Tredgold states that the condenser gauge should indicate the state of the vapour in the condenser, to be capable of sustaining from two to three inches of mercury; that,

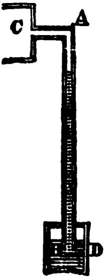

Fig. 59.

while it does not exceed three inches, the condensation may be esteemed very good, and that about two inches is the best he has seen obtained in practice. The force by which the motion of the piston is determined, is, therefore, ascertained by reference to the steam gauge, and the condenser gauge: the difference between the elastic force of the steam in the boiler, and that in the condenser, added to the height of the barometer at the time, will indicate the relative force of the steam to work the engine. From the resemblance of the condenser gauge to the common barometer, it is frequently called the *barometer gauge.*

92. *The Indicator.*—But the force of the steam in the cylinder, and the state of exhaustion in the condenser, vary at different portions of the stroke of the engine, and these variations cannot be ascertained by means of the two gauges already described; the mercurial column would be affected by constant vibrations, corresponding with these variations, and it would be impossible to ascertain its mean height during the stroke. To obviate these difficulties, Watt employed an instrument called an *indicator.* It consists of a cylinder C of about an inch and three quarters in diameter, and eight inches in length, of very uniform calibre; it terminates below in a pipe, to which a small cock D is adjusted. A solid piston is accurately fitted to the cylinder, so as to move steam-tight within, by the means of oil; the piston-rod G is about five-eighths of an inch in diameter, and sixteen inches in length; to prevent any jar or friction, the rod is made to pass through a guide, H, at a distance of about six inches from the top of the cylinder; the upper part of the piston-rod forms an index, M, which moves upon a graduated scale, K. A spiral spring, I, is attached to the piston, and to the guide H; it is about seven inches in length when at rest, and admits of being compressed an inch and a half;

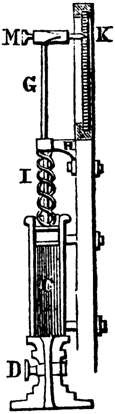

Fig. 60.

its strength is such as to admit of the piston being carried down to within about an inch of the bottom of the cylinder, when loaded with fifteen pounds on the square inch. This instrument is screwed upon the steam cylinder of the engine, and a communication is thus effected between the upper part of the steam cylinder, and the lower part of the indicator cylinder. The steam on being admitted into the former cylinder, rushes into the latter, and, if its force be greater than that of the atmosphere, the indicator piston rises, and its index marks the degree of pressure on the affixed scale; as the steam piston descends, the indicator piston varies its position with the varying pressure of the steam in the steam cylinder, and these variations will be indicated on the scale. By substituting a pencil for the index, and placing a sheet of paper so as to move horizontally, these variations may be recorded on the paper in the form of curved lines. A diagram of this kind, showing the practical application of the Indicator to ascertain the effective power of a steam engine, as given by Mr. Glynn, may be seen in the appendix to Tredgold, p. 169; it is a fac-simile of that traced by the instrument. Mr. Glynn observes that the indicator shows not only the relative action of the vacuum and pressure of the steam upon the piston of an engine, but their absolute force and effect; it shows how much of that force is taken to overcome the friction of the machine, and produce the change of motion in its parts, and how much is available for useful purposes; it exhibits, if we may so say, the disposable force of the steam engine, and the perfection or imperfection of its construction or condition at the time of making the trials.

RECAPITULATION.

75. By what circumstances are the proportions of a steam cylinder regulated? What relation should the length of the

cylinder bear to its diameter? Explain Tredgold's plan for preventing the cooling effect of the atmosphere on cylinders? —76. What two conditions are indispensable in the construction of a piston? What is meant by a *stuffing-box?*—77. Explain the construction of the hemp-packed piston. What is the amount of friction produced by the action of such a piston?—78. Describe Woolf's contrivance for tightening the packing of the piston.—79. What improvement was introduced in the construction of the piston by Cartwright? Explain the general construction of a metallic piston.—80. What is a valve? How may the valves employed in steam engines be arranged? On what does the efficiency of a valve depend?—81. What is the construction of the common *clack valve?* In what parts of the steam engine is it found? In what part of the engine is the *double clack valve* found? At what degree of inclination should the clack valve open?—82. How is the *conical valve* formed? In what part of Watt's engines are they found? What are the proper dimensions of this valve? At what angle should it fit in its seat?—83. Explain the construction of the spherical valve.—84. What is the nature of a *slide?* What advantage does the use of a slide possess over that of rising valves? Explain the construction and operation of *Murray's slide.* How are the effects of friction obviated in this form of slide?—85. What is the objection to Murray's slide? How is this objection obviated by *Murdock's slide?* Explain the construction and operation of this slide.—86. Explain generally the construction of *Seaward's slides?* What are the advantages of this apparatus?—87. Explain the nature of a *throttle valve.*—88. Explain the mechanism of the single cock.—89. What is the object of the *four-passaged cock?* How is it modified in *expansive* engines?—90. By what mechanism were the valves formerly opened and closed? Describe the construction and the action of the *eccentric.*—91. Explain the nature of the *condenser gauge.* —92. In what respects are the steam and condenser gauge defective? Describe the use of the *indicator.*

CHAPTER VIII.

OF THE MECHANICAL POWER OF STEAM, AND OF THE POWER AND DUTY OF ENGINES.

93. *Preliminary Remarks.*—In the two foregoing chapters, the various parts of the modern steam engine have been *severally* examined, preparatory to the consideration of their *combined* action and relation to each other in the entire machine. The present chapter will be devoted to the investigation of certain laws by which the *mechanical action of steam* is determined or modified; to the modes of obtaining the different species of power of steam to produce useful effect, as by generation, condensation, expansion; and to the explanation of some important expressions connected with the *power and duty of steam engines.* These subjects will be noticed in the following order:—

1. *Relations existing between the*
    1. *Pressure,*
    2. *Temperature, and*
    3. *Density of Steam.*

2. *Modes of obtaining Power from Steam.*

3. *Mechanical effect of Steam Engines.*
    1. *Theory of M. de Pambour.*
    2. *Power of engines; horse power.*
    3. *Duty of engines.*
    4. *Cornish engines.*

94. *Relation between the Pressure, Temperature, and Density, of Steam.*—Steam may exist in two conditions: it may be in contact with the water from which it is generated; or it may be separated, and exist apart, from the water. The properties which steam exhibits in these two conditions are very distinct. This subject has been already noticed (pp. 10,77); some further observations are, however, necessary, in order to understand the general laws which regulate the mechanical effects of steam, and the value of certain expressions which are in common use in all calculations of steam power. The first point to be considered is, the *pressure of steam as influenced by temperature.* By the term 'pressure,' or tension, is denoted the elastic force with which steam presses upon every point of the surface of the vessel which contains it; its 'temperature' is ascertained by the number of degrees indicated by a thermometer immerged in it. Steam, when heated in a vessel apart from the liquid which generates it, does not acquire a greater pressure than an equal bulk of common air which is confined and heated to the same degree; it may even be heated to redness, without greatly increasing its pressure. But, when heated in contact with water, its pressure continually increases, and in a certain ratio. Numerous experiments have been instituted by celebrated chemists, in order to determine the relation which subsists between the pressure of steam, still in contact with water, and the temperature to which it is exposed. The most satisfactory results are those obtained by a commission of the French Academy, appointed by the French government to investigate the subject, owing to its importance in connexion with the steam engine. The researches were conducted on a vast scale, and with the greatest accuracy. The pressure of the steam was measured by columns of mercury in glass tubes of eighty-seven feet in height. The results are stated below in the form of a table, for the purpose of reference. The *pressure* of the steam is referred to the standard of atmospheric pressure, or fifteen pounds on the square inch, which is here assumed as unity; the *tempera-*

ture is denoted by degrees of Fahrenheit's thermometer. The results, up to a pressure of 25 atmospheres, were obtained by experiment; above this pressure, they were obtained by calculation :—

Pressure of Steam, taking atmospheric pressure as unity.	Temp. Fahr.
1	212.0
1½	233·96
2	250·52
2½	263·84
3	275·18
3½	285·08
4	293·72
4½	300·28
5	307·5
5½	314·24
6	320·36
6½	326·26
7	331·70
7½	336·86
8	341·78
9	350·78
10	358·88
11	366·85
12	374·00
13	380·66
14	386·94
15	392·86
16	398·48
17	403·82
18	408·92
19	413·78
20	418·46
21	422·96
22	427·28
23	431·42
24	435·56
25	439·34
30	457·16
35	472·73
40	486·59
45	491·14
50	510·60

The relation subsisting between the pressure and temperature of steam, as above stated, is closely connected with another point, the knowledge of which is of great practical utility, viz. the *density* of steam generated under a given pressure. Steam, when heated in a vessel apart from the water which generated it, increases in pressure, and retains its density. But when steam is heated in contact with water, it increases considerably in pressure, and its density increases in proportion ; in other words, the volume of steam bears a certain relation to its pressure. It has been found, by experiment, that the *volume of all elastic fluids is inversely as the pressure to which they are exposed,* the temperature remaining the same. Thus, if 100 volumes of steam, at 212°, could be compressed into 50 volumes, and the temperature remain unaltered, the pressure would be increased in a twofold proportion, while the bulk of the steam would be reduced to half its former dimensions. If, on the other hand, the pressure on the 100 volumes of steam were halved instead of doubled, the 100 volumes would expand into 200, while the pressure would be reduced to half its former amount.

95. *Application of the preceding Law.*—The preceding *law* would be applicable to steam, if the annexed condition could be observed, viz. *if the temperature were constant.* But this is not the case: the temperature of the steam varies with its expansion or compression. In proof of this may be adduced the result of a series of experiments, instituted by the Comte de Pambour. He adapted to the boiler of a locomotive engine a thermometer and an air-gauge, and applied two similar instruments to the pipe through which the steam, after having terminated its action in the engine, escaped into the atmosphere, and observed their simultaneous indications. "The steam was generated in the boiler at a total pressure varying from 40 lbs. to 65 lbs. per square inch, and escaped into the atmosphere at a pressure varying, according to different circumstances, from 20 lbs. to 15 lbs. per square inch. Had the steam preserved its temperature during its action in the engine, it would have issued forth with the pressure, for instance, of 15 lbs. per square inch, but with the temperature proper to the pressure at which it had been formed, that is, 65 lbs. per square inch. Now, nothing like this took place: during some hundreds of experiments wherein we observed and registered these effects, we found invariably that the steam escaped precisely with the temperature suitable to its actual pressure; so that the thermometer, graduated to indicate the pressure in the steam of maximum density, gave identically the same degree of pressure as the air-gauge. The steam, then, was generated in the boiler at a very high pressure, and quitted the engine at a very low one; but, on its leaving the engine, as well as at the moment of its pro-

duction, the steam was at the same temperature that it would have had, if immediately formed at the pressure which it had at the moment of observation. Consequently, we are to conclude from these experiments, that during its whole action in the engine, the steam remains in the state of steam at the maximum pressure or density for its temperature. Hence it results that, when the pressure of the steam changes in the engine, its temperature changes spontaneously at the same time, and *vice versâ;* so that they always preserve the mutual relation which connects the pressures and temperatures in the steam in contact with the generating liquid."* In calculating the mechanical effect of an engine, it is therefore necessary to take into account the operation of the *two following laws* :—first, that, the temperature being constant, the pressure of steam is proportional to its density; and, secondly, that, the temperature being changed, there is a corresponding change of pressure, and consequently a change in its mechanical effect.

96. *Modes of obtaining Power from Steam.*—It has been shown, in the foregoing chapters, that there are various modes of employing steam; its mechanical effect varies with its different modes of employment. 1. When steam is generated at 212°, or at the *atmospheric pressure*, it is evident that no power is obtained: the weight of the atmosphere is merely balanced. This will be evident, by referring to the figure at page 14; if steam of merely atmospheric pressure be generated beneath the piston, it has no power to raise the piston; it merely places it in a passive condition, and a counter weight is employed to produce useful effect. 2. When steam is *condensed*, as in the atmospheric engine (p. 27), mechanical force is obtained; but in this case it is obtained by giving effect to a foreign agent: a vacuum is produced by the condensation of steam, and the piston descends under the pressure of the atmosphere. 3. In the single acting engine (p. 40), one half of the stroke is effected by the direct

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* *Theory of the Steam Engine*, Weale, 1839.

pressure of the steam above, aided by a vacuum beneath, the piston; the piston is then placed in a state of repose by the admission of steam below as well as above it, and the other half of the stroke is effected by means of a counter-weight. 4. In the double acting engine (p. 60), each part of the stroke is effected by the direct pressure of the steam, aided in each case by the production of a vacuum. 5. If, in addition to the atmospheric pressure, a load be placed upon the piston, and steam be generated beneath it, the loaded piston will be raised to a height proportionably smaller as the load is greater (fig. p. 65), and the volume of the steam will be inversely as the resisting pressures, the temperature being constant, according to the law above stated; thus, if the resisting pressures be four times that of the atmosphere, the piston will be raised only one-fourth of the height, and so on. On the other hand, when this steam is condensed, the piston descends with fourfold force. Thus, whether the steam be generated at merely the atmospheric, or at a higher pressure, the effect obtained by its generation and by its condensation, is the same at the same temperature. 6. In a common *high-pressure* engine, the steam, after raising the piston, is discharged through a valve into the air, and the power gained in the preceding case by condensation is lost; and this loss is equal to the pressure of the atmosphere acting on the piston throughout its descent. 7. By another mode of obtaining power, already described (p. 65), the *usual* effect of a given quantity of steam in raising a piston is first secured; the steam is then cut off, and suffered to *expand* until it is reduced to the elastic pressure of the atmosphere; an *additional* effect is thus obtained in one part of the stroke, while none is lost in the other, for the condensation of the steam produces the same effect as if it had been generated of atmospheric pressure at first. This mode of employing steam combines the principles of the high-pressure, and of the condensing, engine, and secures their joint effects; when steam of very high pressure is employed, and its supply cut off early in the stroke, its effect is nearly doubled. There are other modes of gaining power by the *expansive* action of steam, as by removing the load, wholly or in part, when the steam is cut off; or by removing portions of the load at different parts of the stroke; or, lastly, by adding counterweights during the ascent, and removing them during the descent, of the piston, as in the expansive engines of Watt and Hornblower, already described.

97. *Mechanical Effect of Engines.*—In determining the mechanical effect of engines, a distinction must be made between the *total effect*, and the *useful effect;* in other words, between the pressure of the steam in the boiler, and the power of the steam in overcoming the resistance, or load, of the engine. There are several circumstances which *reduce* the effect of the steam, during its transmission through the engine: these are, the friction of the engine itself; and the loss of power resulting from the waste of steam,* its partial condensation, its passage through narrow tubes, its change of direction in the tubes, &c. The *loss of effect* produced by these causes, in a non-condensing engine, was computed by Tredgold at four-tenths, including the atmospheric pressure, which would make a reduction of five-tenths on the *useful effect* of such an engine. How far this estimate was correct with reference to the engines on which Tredgold experimented, we are unable to say; but it very much exaggerates the loss of effect in engines of more modern construction and capabilities. Tredgold's mode of calculation has been recently attacked by M. de Pambour, who proposes another theory for estimating the effects of steam engines. As there appears to be a difference of opinion respecting the 'novelty' of this theory, it is stated in the following paragraphs in the words of M. de Pambour himself, taken from the work already quoted.

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* It is obvious that there will be, at every stroke of the engine, a certain quantity of steam in the valve-boxes and tubes connected with the cylinder, and that this quantity will be inefficient, and should therefore be placed to the account of loss of power. This quantity of steam is called *clearance.*

98. *Theory of M. de Pambour.*—In stating this theory, M. de Pambour supposes the steam to preserve the same temperature throughout its action in the engine, limiting himself to rotative engines without expansion, and taking his basis on the consideration merely of the uniform motion which the engine necessarily attains after a very short time.

"It is well known that in every machine, the effort of the mover first being superior to the resistance, a slow motion is produced, which accelerates gradually till the machine attains a certain velocity which it does not surpass, the mover being incapable of sustaining a greater velocity with the mass it has to move; the machine having once attained this point, which requires but a very little time, the velocity continues the same, and the motion remains uniform during the rest of the work. It is but from this moment, viz. the commencement of uniform motion, that the effects of machines begin to be calculated; and the few minutes during which the velocity regulates itself, or the transitory effects from the velocity null to uniform velocity, are always neglected.

"Now in every machine which has attained a uniform motion, the power is strictly in equilibrio with the resistance; for were it greater or less, there would be acceleration or retardation of motion, which is not the case. In a steam engine, the force applied by the mover is no other than the pressure of the steam *against the piston* or *in the cylinder*. This pressure then, in the cylinder, is strictly equal to the resistance opposed by the load against the piston.

"Consequently, the steam in passing from the boiler into the cylinder changes its pressure, assuming that which represents the resistance to the piston. This principle, of itself, explains all the theory of the steam engine, and in a manner lays its play open.

"It becomes, in fact, easy to render an account of what passes in a steam engine set in motion. The steam confined in the boiler, at a certain degree of pressure, as soon as the regulator or distributing-cock is open, rushes into the steam pipes, and from thence into the cylinders. Arriving in the cylinder, whose area is much greater than that of the pipes, the steam dilates at first, losing proportionally a part of its elastic force; but as the piston is as yet immoveable, and as the steam continues to flow in rapidly, the balance of pressure is soon established between the two vessels; and the piston, urged by all the force of the steam, begins slowly to move. The fly-wheel of the engine, its entire machinery, and the resistance opposed to it, begin then to acquire a small velocity, which accelerates by insensible degrees; and if at the end of the stroke of the piston, the coming vapour were suddenly withheld, the piston would not stop instantaneously on that account; it would itself be impelled for some time by the effect of the velocity previously communicated to the mass. The result of this is, that at the following stroke, the steam finds the piston already slowly receding, at the moment it impresses thereon a new quantity of motion; which again passes on to the fly-wheel, and to the total mass, where it continues to accumulate. Receiving thus, at every stroke, a new impulse, the piston accelerates its motion by degrees, and, at length, acquires all the velocity the motive power is capable of communicating to it.

"During all this time the steam continues to be generated in the boiler with the same rapidity, and to flow into the cylinder, but as the piston acquires a quicker motion and developes a greater volume before the steam, the latter dilates, assuming a lower pressure, till at length, the piston having assumed all the velocity that the steam can impress upon it, with the load that it supports, the pressure of the steam in the cylinder becomes equal to the resistance of the piston, and the motion remains in a state of uniformity."—Pp. 19—21.

99. *Power of Engines; Horse Power.*—The 'useful effect' of an engine being determined, its amount is usually expressed by reference to some standard of comparison. It has been stated (p. 47) that the earliest engines were merely pumps, worked by steam, instead of by 'horses.' The *power* of an engine would, therefore, be naturally expressed by comparing its performance with the work usually done by one

or more horses: and, hence, an engine is said to be of one or more, *horse power*. Some difference of opinion has existed as to the amount of work which a horse is able to perform; but this is of little consequence, as the term has now become conventional, and the standard of power recognised by the manufacturers of engines. It has been decided that the power of an average horse, working eight hours a day, is equal to 33,000 lbs. raised one foot per minute; when an engine, therefore, is said to be of *one horse power*, the expression means that the engine is capable of moving such a load through a space of one foot per minute; for every extra horse, an equal number of pounds is supposed to be added to the resistance of the engine. In one of Smeaton's engines, the diameter of the cylinder was eighteen inches, its surface 324 circular inches, and he estimated its power at 7 pounds on the inch, or 2268 pounds; the number of strokes per minute was ten, of six feet each; the power of the engine was, therefore, equal to the number of pounds, multiplied by the number of strokes per minute, and by the number of feet in the stroke; thus, $2268 \times 10 \times 6 = 136080$ lbs.; his engine was, consequently, of *four horse* power. It has been stated (p.14) that the mechanical force produced by the evaporation of a cubic inch of water is sufficient to raise about a ton weight to the weight of one foot; and as 33,000 lbs. amount to nearly fifteen tons, we are prepared to admit that the mechanical force produced by the vaporisation of fifteen cubic inches of water per minute, is equal to what is technically called a *one horse* power. The knowledge of this fact renders it an easy matter to supply an engine with water, in quantities proportioned to its power, that is, with 900 cubic inches per hour for each horse power. The reader is now referred back to the interesting applications of heat, stated at pp. 15, 16, of this work.

100. *Duty of Engines.*—The 'power' of an engine is estimated, as above described, by the mechanical effect produced in a certain *time*. By the 'duty' of an engine, is signified the mechanical effect produced by a certain quantity

of *fuel*, without reference to time. Hence, the *power* of one engine may be much greater than that of another, while its *duty* is equal, or even less: the amount of steam produced by two engines from the same quantity of fuel may be the same, and the duty of the engines will then be equal; but the engine which produces this effect in the shorter time, is said to have the greater power. The duty of an engine obviously depends on a combination of various circumstances; those connected with the construction of the boiler, the furnace, and its appendages, have been sufficiently investigated in the two preceding chapters. The quantity of fuel required for the due performance varies, also, with the form and size of the engine, and the purpose to which it is applied. Smeaton considered, that a two feet cylinder requires 174 lbs. of Newcastle coal per hour; this calculation would give 97½ lbs. per hour for the eighteen inch cylinder, mentioned in the last paragraph; but he was of opinion, that an engine of four horse power, of similar construction, could be worked by as small a quantity as 65 lbs. per hour. In double acting engines, working without expansion, the quantity of coal required per hour, varies from 7 to 12 lbs. The average consumption of fuel in the best marine engines was stated by Dr. Lardner at about 8 lbs. per hour for single horse power, but he considers this estimate only as an approximation liable to several causes of error. The subject requires further investigation.

101. *Duty of the Cornish Engines.*—Allusion has been made (p. 67) to the engines employed for draining the Cornish mines. These are generally single acting engines, in which steam is worked on the expansive principle. In 1811, these engines were placed under the superintendence of an eminent engineer, and monthly reports were published, embracing the following particulars:—The size of the cylinder, the load on each square of the cylinder, and the length of the stroke; the number of strokes of the pump, the diameter of the pump, and the depth of its stroke; the time consumed; the consumption of coals in bushels, and the number of

strokes during the consumption, &c. The number of engines, reported on, was, at that period, twenty-one; they have since increased to sixty-one. The rate of duty performed is expressed by the number of pounds raised to a height of one foot by the consumption of one bushel of coal. The results of the inquiry, for 1826, are given in a tabular form in Tredgold's work, from which a single extract will be here sufficient: the duty of a single engine, working on the Wheal Hope Mine, with a cylinder of 60 inches diameter, load per square inch on the piston 8·37 lbs., length of the stroke 9 feet, number of strokes per minute 5·5, &c., was upwards of 46,000,000 lbs. raised one foot by the consumption of one bushel of coal. However surprising such an effect may appear, it has been far exceeded by the improved condition of the engines under this efficient mode of inspection. The average of ten of these engines has more recently realized a duty of 70,000,000; and even greater results than this have been recorded on unquestionable authority.

RECAPITULATION.

94. In what two conditions does steam exhibit very different properties? Is the *pressure* of steam, confined in a vessel apart from water, materially influenced by increased *temperature?* What is the effect of increased temperature upon steam, when in contact with water from which it is generated? What effect has heat upon the *density* of steam, in the former condition? What, in the latter? State the *law* of the relation between the *volume*, and the *pressure*, of steam. Illustrate the law.—95. How is this law shown to be inapplicable to steam? State the *two laws* which must be taken into account in calculations of steam power.—96. How is mechanical power produced by condensation of

steam? Describe the production of power, in the engines of Newcomen and Watt. What is the loss of power in a common high-pressure engine? What power is gained in *expansive* engines, beyond the *usual* effects of the steam?—97. What is the difference between the *total effect* and the *useful effect* of an engine? By what circumstances is the useful effect of an engine reduced?—98. Give an account of the theory of the steam engine, as stated by M. de Pambour.—99. What is meant by the expression *horse power?* What is the performance of a horse, per day? What amount of vaporisation is equal to one horse power?—100. What is the difference between the *power* and the *duty* of engines? What is the average consumption of fuel required for each horse power?—101. State the amount of duty which has been performed by the Cornish engines.

CHAPTER IX.

OF LOCOMOTIVE ENGINES ON RAILWAYS.

102. *Preliminary Remarks.*—The numerous applications of steam power to the purposes of impelling machinery in printing, manufacturing, and agricultural operations, will be passed over; there are comparatively few to whom these processes are of great interest, and those few must seek information in larger and more elaborate treatises than the present. But the extraordinary changes which the interests and relations of society are undergoing in the present day by means of steam *locomotion*, render the subject one of educational importance to every member of a civilized community. Who, in the present day would willingly avow his ignorance of the application of steam to the whole science of *navigation*—"that new and mighty power," to use the eloquent language of Canning, "new at least in the application of its might, which stalks the water like a giant rejoicing in its course—stemming alike the tempest and the tide—accelerating intercourses, shortening distances; creating, as it were, unexpected neighbourhoods, and new combinations of social and commercial relation; and giving to the fickleness of winds and the faithlessness of waves, the certainty and steadiness of a highway upon the land?" The truth contained in these words may be illustrated by a single fact,—a fact which in other days would have been treated as a tale of romance: a vessel may now navigate the Atlantic, between England and New York, within the space of fifteen days, and this, without stopping at any intermediate port!

Again; on the subject of *inland transport*, Dr. Lardner asks,—" Who could have credited the possibility of a ponderous engine of iron, loaded with some hundred passengers, in a train of carriages of corresponding magnitude, taking flight from Manchester and arriving at Liverpool, a distance of above thirty miles, in little more than an hour? And yet this is a matter of daily and almost hourly occurrence. The rapidity of transport thus attained is not less wonderful than the weights transported. Its capabilities in this respect far transcend the exigencies even of the two greatest commercial marts in Great Britain. Loads, varying from 50 to 150 tons, are transported at the average rate of 15 miles an hour; and in one instance we have seen a load—we should rather say a *cargo*—of waggons, conveying merchandize to the amount of 230 tons gross, transported from Liverpool to Manchester at the average rate of 12 miles an hour."—*Treatise on the Steam Engine*, p. 329.

Once more; if any thing further were wanting to show the rapidity with which both land and sea transport may be performed by means of railroads, steam engines, and paddle wheels, the excursion performed on September 21, 1841, under the arrangement of the directors of the Southampton Railway, would supply it. On that day, seven carriages, each containing twenty-four persons, left London at a few minutes before seven in the morning, and reached Southampton at a quarter past nine. At ten o'clock the Grand Turk steam boat left the pier of this town, and conveyed the passengers down the Southampton water, and entirely round the Isle of Wight, returning to Southampton by half past five o'clock. The company, after amusing themselves for an hour and a half at Southampton, entered the carriages of a special train at seven o'clock, and reached London at thirty-five minutes past nine, having thus performed a trip of nearly 250 miles, including sea and land, in little more than 14 hours and a half; a trip which a few years ago would almost have taken as many days. The whole excursion cost each person only twenty shillings.

The present chapter will furnish the reader with a succinct account of the history of the modern engine, as employed for inland transport, in the following order:—

1. *Classification of Steam Engines.*

2. *Early Locomotive Engines.*
    1. *Trevithick and Vivian's engine.*
    2. *Blenkinsop's engine; Rack-rail.*
    3. *Messrs. Chapman's engine.*
    4. *Brunton's Mechanical Traveller.*
    5. *Adhesion of the wheels to the rails.*
    6. *Stephenson's Killingworth engine.*
    7. *Fixed and locomotive engines.*

3. *Recent Locomotive Engines.*
    1. *Liverpool experiments; 'Rocket' engine.*
    2. *Mr. Bury's engines; cranked axles.*
    3. *Dr. Lardner's experiments in* 1832.
    4. *Most recent locomotive engine.*
    5. *Mr. Samuel Hall's improvements.*

4. *Of Rails, and Railroads.*
    1. *Materials and forms of rails.*
    2. *Construction of railroads.*
        1. *Of turn-outs.*
        2. *Of tunnels.*
        3. *Of curvatures.*
        4. *Of gradients.*

5. *Of Resistance on Railroads.*
    1. *Different kinds of friction.*
    2. *Dr. Lardner's experiments in* 1838.
    3. *Compensating effect of gradients.*

6. *Locomotive Engines on Common Roads.*
    1. *Gurney's steam carriage.*
    2. *Hancock's steam carriage.*

103. *Classification of Engines.*—Although it is intended to limit the attention of the reader to the locomotive engine, as at present employed for inland, and marine, transport, a classification of the various steam engines, according to the principle by which they are worked, may be found convenient as a table of reference:—

1. Condensing Steam Engines.
    1. Simple condensation in the cylinder.
        Atmospheric engines.

    2. Simple condensation in the condenser.
        1. Watt's single acting engines.
        2. Watt's double acting engines.
        3. Cornish single acting engines.

    3. Condensation and expansion.
        1. Expansion in one cylinder.
            1. Watt's engines, single and double.
            2. Cornish engines, single and double.

        2. Expansion in two cylinders.
            Hornblower's and Woolf's engines.

2. Non-condensing Steam Engines.
    1. Simple generation of steam.
    2. Generation and expansion of steam.

1. *Engines of the first class* are commonly called *low-pressure* engines; but the term is not in all cases correct, for many of these engines, particularly those which combine expansion with condensation, work with a considerable load upon the safety valve, as in the case of the Cornish engines. The single acting Cornish engine differs, in fact, from Watt's single acting engine merely in the steam being employed, in the former case, at a total pressure of 50 or 55 lbs., and sometimes at 75 or 80 lbs., instead of 16 or 18 lbs. per square inch; and in the expansion of the steam being carried much further, the steam being often cut off, when the piston has performed but one-tenth of the stroke. The term *low-pres-*

sure engine, therefore, frequently conveys a false notion; the term *condensing* engine, on the other hand, always conveys a true one, viz. that the engine is provided with a condensing apparatus. 2. *Engines of the second class* are commonly called *high-pressure* engines. In this case the terms are equally significant: such engines, having no condensing apparatus for the production of a vacuum, are obliged to work with steam of higher pressure than that of the atmosphere. Hence it is evident that high-pressure engines, though remarkable for the simplicity of their construction, never turn to account the whole power of the steam: a portion of this power is necessarily expended in merely balancing the pressure of the atmosphere; and it is the excess of the pressure of the steam above that of the atmosphere which constitutes its power to produce motion. On the other hand, the condenser, the air-pump, the cold water pump, the cold water cistern, &c., are dispensed with; the difficulties attending the injection of condensing water are spared; hence, the high-pressure engine, comprising only a boiler, and a cylinder with its piston and valves, becomes available to purposes, for which its comparatively small size, light form, and simple construction, so admirably adapt it.

EARLY LOCOMOTIVE ENGINES.

104. *Leupold's High-Pressure Engine.*—The earliest experiment of a *high-pressure* engine, worked by a cylinder and piston, was made by Leupold in 1720. His engine, and its mode of action, are noticed at page 31; the four-passaged cock is more fully described at p. 117. Nothing can be more simple than this apparatus: a piston is raised by steam of a high pressure; the steam which has performed this office is discharged into the atmosphere; a continuity of effect being desirable in pumping water, two cylinders are so connected that while the steam from one is escaping into the air, and thus producing no effect, it is acting in the other

cylinder so as to force water into the reservoir at the opposite end of the lever.

105. *Trevithick and Vivian's High-Pressure Engine.*—It is to Messrs. Trevithick and Vivian that we are indebted, in 1802, for the first practical application of high-pressure steam. The earliest experiment of a high-pressure locomotive engine was made in 1804, on a *tram-road** at Merthyr Tydvil, in Wales. The boiler, now called Trevithick's boiler, was of a cylindrical form, with flat circular ends; it was mounted horizontally upon a strong frame with four wheels. A tubular flue entered the boiler at one extremity, and, passing to the other extremity, was there curved upon itself like the letter ⊃ and continued backward in a parallel direction to the extremity at which it entered the boiler; here it terminated in the chimney; the mouth of the flue formed the fire-place and the ash-pit; by this means the hot air from the fire communicated its heat to the water during its forward and backward passage through the flue, previously to its escape into the chimney. There was only one cylinder; this was placed vertically at the extremity opposite to the fire-place, and was partly immersed in the water of the boiler, by which means the temperature and elasticity of the steam were maintained at a high degree. Above the cylinder was placed a four-passaged cock, and communications were thus effected between the boiler and the upper and lower parts of the cylinder; steam was admitted into the upper part, and discharged from the lower part, of the cylinder, and *vice versâ*, alternately. The discharged steam was conveyed by a pipe to the chimney, where it aided the action of the fire-place by increasing the draught, and escaped into the air. The upper end of the piston-rod

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* A *tram-road* is a continuous line of smooth pavement, usually formed of flat rails made of cast iron, with an elevated edge or flange, on one side, to guide the wheels of carriages. It is capable of being used for ordinary wheel carriages.

was attached to a cross-bar, like the letter T; to the extremities of the cross-bar were attached two vertical rods, the lower ends of which worked the cranks of the axle in the usual way. The steam cocks were opened and shut by machinery connected with the crank axle. The motion of the engine was regulated by a fly-wheel. Steam of a pressure of about 70 lbs. was employed in this engine; the danger of explosion was guarded against by the use of fusible plugs, and by the adaptation of two safety valves, one of which was locked up, and thus placed out of the control of the attendant. The performance of this engine consisted in the draught of ten tons of bar iron, together with the necessary carriages, water, and fuel, at the rate of five miles an hour.

106. *Skidding of the Wheels.*—The early efforts at constructing locomotive engines were met by a difficulty, which was afterwards proved to be merely imaginary. It was supposed that the wheels would slip on the road, and would thus continue to turn round, while the engine itself remained stationary; in other words, that there would not be sufficient adhesion between the tire of the wheel and the surface of the road, to propel the carriage. 1. To obviate this *skidding* of the wheels, as it is called, Messrs. Trevithick and Vivian proposed to make the tires of their wheels rugged and uneven, by driving into them large nails and bolts with projecting heads, or by making deep grooves across them, in order that they might take hold, as it were, upon the road, and thus facilitate their ascent in cases of elevation. Such a contrivance would, however, be attended by two very serious objections: first, there would be considerable resistance to the progressive motion of the carriage; and, secondly, the rails of the road would be materially injured. 2. In 1811, a patent was obtained by Mr. Blenkinsop, of Leeds, for the first double cylindered locomotive engine. His boiler was of a circular form, and contained within it a tube, at one end of which was the furnace, and at the other the chimney. His cylinders were vertical, and were principally within the boiler: the piston-rods were furnished with

cross-bars, to which were attached connecting-rods, and these worked the cranks of the axle. His method of preventing the anticipated skidding of the wheels, consisted in the application of a *rack-rail:* one side of the road, throughout its entire length, was constructed with teeth, like those of a cog-wheel; two of the wheels of the engine had their tires provided with similar teeth, which worked in gear with those of the road, and thus the engine was propelled. By means of this rack-rail, the engine was enabled to ascend acclivities; but the motion was, obviously, very rough, and the wear of the wheels considerable; the plan was abandoned, so soon as it was discovered that there was sufficient adhesion of the wheels to the road without it. This engine of Blenkinsop's cost £400; its weight was about 5 tons; it consumed 50 gallons of water and 75 lbs. of coal per hour; its performance was 94 tons drawn on a level at 3½ miles per hour; its maximum speed was 10 miles per hour. 3. In 1812, another contrivance for obviating the imaginary skidding of the wheels, was adopted by Messrs. Chapman. A chain was extended along the middle of the railroad, from one end of it to the other, and made fast at each end, and at convenient intervals; the chain was passed once round a wheel fixed beneath the centre of the carriage, in such a manner that when the wheel was set in motion by the engine, the chain was incapable of slipping upon it, and the carriage was necessarily propelled in the line of the chain and road. In this case, however, a serious loss of power was incurred by the friction produced by the chain. 4. In the following year, an extraordinary contrivance was introduced by Mr. Brunton for surmounting the alleged difficulty. It consisted in attaching to the engine a pair of propellers, resembling in their action the legs and feet of an animal; these were adapted to lay hold on the ground at each stroke of the engine, and thus afford a resistance, the re-action of which caused the engine to advance. This "mechanical traveller," as the patentee termed it, required a power of eighty-four pounds to move it at the rate of two miles and a half per hour. The machine being placed on a railway, and a chain applied to the back part of it, for the purpose of raising a weight as the engine was advancing, it was found that with steam equal to forty or forty-five pounds' pressure on the square inch, the engine was propelled at the rate of two miles and a half per hour, and raised perpendicularly 812 lbs. at the same speed; thus making the whole power equal to 896 lbs. at two miles and a half per hour, or nearly that of six horses.

107. *Adhesion of the Wheels to the Rails.*—The contrivances mentioned in the preceding paragraph were abandoned at this period, as it was now ascertained that there is sufficient adhesion between the wheels and the rails to propel an engine with a heavy load of carriages, along a road which is level, or moderately inclined, without any aid whatever. By experiments on the Wylam railroad, Mr. Blackett found that the adhesion was sufficient for the purpose in all kinds of weather, except when the surface of the rails was covered with snow; that, when the surfaces of the rails, and of the wheels, are either quite dry, or completely wet, the adhesion is the greatest, the surface being then most free from all extraneous matters; that when the rails, on the contrary, are moistened with wet, and partially covered with mud, the adhesion is the least; and that, in all the intermediate states of the rail, the adhesion becomes greater or less, according as its state approximates, more or less, towards either of these conditions. The experiments, by which the amount of adhesion was determined, are described in Wood's Treatise on Railroads. The author of this valuable work, on reviewing these experiments, considers the adhesion, exclusive of the power requisite to drive the engine itself, in the best or modern machines, as equal to the one-fifteenth part of the insistent weight; and in the common engines, working with vertical cylinders, as equal to the twentieth part of the weight, pressing on the rails by the driving wheels.

108. *Stephenson's Killingworth Engine.*—The amount of adhesion between the wheels and the rails having been deter-

mined, it is interesting to trace the methods by which *the power of the engine was communicated to the wheels*, and the progressive motion of the machine effected. In 1814, Mr. George Stephenson constructed an engine for the Killingworth colliery; it had a cylindrical boiler, with a tubular flue passing through it, and two cylinders. The mode by which it was propelled is shown in the subjoined figure.

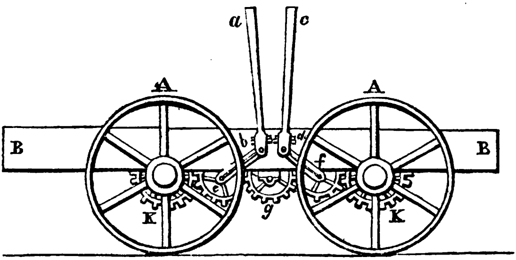

Fig. 61.

A A are the wheels of the carriage, supporting the engine; B B is the frame of the engine, supporting the boiler; *a b* and *c d* are connecting-rods, by which motion is communicated from the piston-rod to the crank, as in the fig. p. 148; *b e* and *d f* are the cranks which turn the two cog-wheels *e* and *f;* the cranks are so adjusted as to be at right angles to each other, so that when one of them is at the stationary points, the other is at the points of its most energetic action (see pp. 55, 56); and this adjustment is secured by the interposition of another cog-wheel *g*, of the same size, which works into the two cog-wheels *e* and *f.* Two larger cog-wheels K K are fixed upon the axles of the carriage wheels; the smaller cog-wheels turn the larger cog-wheels, and these, as they revolve, turn the driving wheels of the engine at the same time. This engine was found to draw after it, on a rail with an acclivity of about one yard in 450, eight loaded carriages, weighing altogether about 30 tons, exclusive of its own weight, at the rate of four miles per hour.

109. *Improved Form of the Killingworth Engine.*—In 1815, a patent was obtained by Messrs. Stephenson and Dodd for an improved form of the engine, in which it was proposed to get rid of the jerking motion, and other inconveniences caused by the cog-wheels. With this view, the crank-pin is connected *immediately* with one of the spokes of the engine wheels, by means of a ball-and-socket joint. In the following figure, A represents the cylindrical boiler; C C the two cylinders; at the top of each of the piston-rods is a transverse rod, to either extremity of which is fixed a connecting-rod; the connecting-rods are seen attached at F and G to one of the spokes of the driving wheels. The action of these cranks is maintained at right angles to each other, by means of an endless chain, which was made to pass over a toothed wheel, D and F, placed on each axle between the driving wheels. An ingenious contrivance was introduced into this engine. The machine was made to rest upon *steam springs.* The patentees thus speak of this improvement:—" Our invention consists in sustaining the weight, or a proportion of the weight, of the engine upon

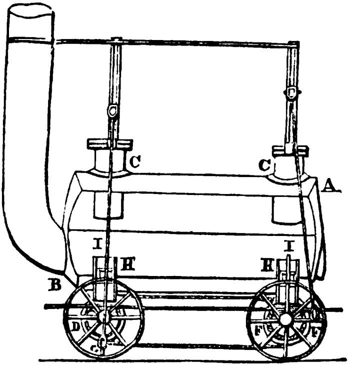

Fig. 62.

pistons, moveable within cylinders, into which the steam or water of the boiler is allowed to enter, in order to press upon such pistons; and which pistons are, by the intervention of certain levers and connecting-rods, or by any other effective contrivance, made to bear upon the axles of the wheels of the carriage, upon which the engine rests." These cylinders are represented in the fig. at H H; they are screwed by flanges to one side of the boiler, into which they project a few inches; they are open above where they communicate with the steam or water in the boiler; they are also open below, where they are fastened upon the frame of the engine. Solid pistons I I are fitted steam-tight to the cylinders; the piston-rods are directed downward, and fastened over the axles of the wheels, upon a moveable part of the frame. By this contrivance, the engine is entirely supported by the steam, which forms a spring of the nicest elasticity. Ingenious as this invention is, it is of little practical utility; for, when the steam loses the requisite elasticity for supporting the engine, the pistons are forced upwards into the cylinders, and the steam suspension is destroyed. Modifications of the engine, now described, were adopted: the endless chain was laid aside, and the axles of the driving wheels were cranked by means of a horizontal connecting-rod, a plan which will be more fully described hereafter; but, in the most improved state of the engine, as employed until the year 1829, its maximum performance was to convey forty tons at the rate of six miles per hour; the evaporating power of the boiler being equal to about fifteen gallons of water per hour.

110. *Fixed and Locomotive Engines.*—In the spring of the year 1829, the Liverpool and Manchester Railway being far advanced towards completion, the directors appointed Messrs. Walker and Rastrick to institute an inquiry into the comparative merits of fixed and locomotive engines, with reference to expenditure, and the capabilities of the machines. Their report contained the following statement:—"Upon the consideration of the question in every point of view,

taking the two lines of road as now forming; and having reference to economy, despatch, safety, and convenience, our opinion is, that if it be resolved to make the Liverpool and Manchester Railway complete at once, so as to accommodate the traffic as stated in your instructions, or a quantity approaching to it, the stationary reciprocating system is the best." Notwithstanding this report, a majority of the directors appeared to be in favour of locomotive engines, provided they could be made of sufficient power, of less weight than those hitherto employed, and capable of consuming their own smoke. A second inquiry was instituted by Messrs. Stephenson and Locke, and with a different result, founded on the increased power gained in the construction of locomotive engines subsequently to the date of the previous inquiry. The two estimates are given in detail in Wood's Treatise on Railroads. The comparison of the two kinds of engines, according to the latter estimate, is as follows:—

Engines.	Capital.	Annual Expense.	Expense of taking a Ton of Goods One Mile.
	£ s. d.	£ s. d.	
Locomotive	58,000 0 0	25,517 8 2	0·164 of a penny
Stationary	121,496 7 0	42,031 16 5	0·269 ,,
Locomotive, less	63,496 7 0	16,514 8 3	0·105 ,,

Messrs. Stephenson and Locke observe:—"That, in considering the long chain of connected power of the stationary engines, given out by so many machines, with the continual crossings of the train from one line to the other, and subject to the government of no fewer than 150 men, whose *individual* attention is *all* requisite to preserve the communication between two of the most important towns in the kingdom,—we cannot but express our decided conviction, that a system which necessarily involves, by a single accident, the stoppages of the whole, is totally unfitted for a public railway." To the same effect is the following opinion of Mr. Walker:—" The probability of accident, upon any *particular part* of the system, is, I think, less with the stationary, than with the locomotive; but, in the former, the effects of an accident extend to the *whole line*, whereas, in the latter, they are confined to the *particular engine and its train*, unless they happen to obstruct the way, and prevent others from passing. The one system is like a number of short unconnected chains; *the other resembles a chain extending from Liverpool to Manchester, the failure of one link of which would derange the whole.*"

RECENT LOCOMOTIVE ENGINES.

111. *Liverpool Experiments.*—The nature of the moving power having been decided in favour of the locomotive engine, a premium of £500 was offered, in April, 1829, by the directors of the Liverpool and Manchester Railway, for the best locomotive engine, subject to certain stipulations and conditions. The principal of these were, that the engine must " effectually consume its own smoke;" that the weight of the machine, with its complement of water in the boiler, must, at most, not exceed six tons; that the load, attached to the engine, must be three times the weight of the engine; that the engine and boiler must be supported on springs, and rest on six wheels, if their weight amounted to six tons; that a machine of less weight would be preferred, if capable of drawing after it a proportionate weight, and that such a machine, if reduced to a weight of four tons and a half, or under, might be placed on four wheels; that the pressure of steam in the boiler was not to exceed 50lbs. per square inch; and that the price of the engine, which

might be accepted, was not to exceed £550, delivered on the railway. The day fixed for the trial was the 6th of October following; the place appointed for the trial was a level piece of road, of a mile and three quarters in length, at Rainhill. The distance to be performed was 70 miles, or twenty trips forward and backward. The engine was to accomplish this in two journeys of ten trips, or 35 miles each, which would be equal to the travelling from Liverpool to Manchester, and back again; between the trips, the engine was to be supplied with fresh fuel and water. The average rate of travelling was not to be less than ten miles per hour. The following engines were competitors for the prize:—

Engine.	Maker.
Rocket . . .	Robert Stephenson.
Sans Pareil . . .	Hackworth.
Novelty . . .	Braithwaite and Erickson.
Perseverance . . .	Burstall.
Cyclopede . . .	Brandreth.

Of these engines, the "Cyclopede" was a horse-machine; it was therefore not qualified to compete for the prize; its performance was only six miles per hour. The "Perseverance" was, after a short trial, withdrawn by its owner, as being unsuited for the purposes of the Company. Three competitors only remained; the construction and performance of the rival engines are described in the following paragraphs.*

112. *Stephenson's "Rocket" Engine.*—The "Rocket" Engine of Mr. Robert Stephenson, the engineer of the London and Birmingham Railway, was first put upon trial. The

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* The reader who may be interested in the "Liverpool Experiments," will find them described, with minute details and tabular arrangements, in the valuable work of *Wood on Railroads*, 3d edit. 1838.

weight of the engine, with the tender and the load, was as follows:—

	Tons	cwt.	qrs.	lbs.
Engine	4	5	0	0
Tender, with water and coke .	3	4	0	2
Two carriages, loaded with stones	9	10	3	26
Total Weight . .	17	0	0	0

This engine performed the first trip of 35 miles in 3 hours 11 minutes and 48 seconds, being at the rate of upwards of 11 miles an hour; and, after taking in a fresh supply of water and coke, it performed the second half of its task in 2 hours 57 minutes and 9 seconds, being at the rate of upwards of twelve miles an hour; this speed included the stoppages at the two ends of the trial ground. Had the 70 miles been performed in a continued line, the performance would be estimated at 17 tons, including the engine, in about five hours, or at the average rate of 14 miles per hour; the water evaporated, 114 gallons per hour; the consumption of coke, 217 lbs. per hour. The general appear-

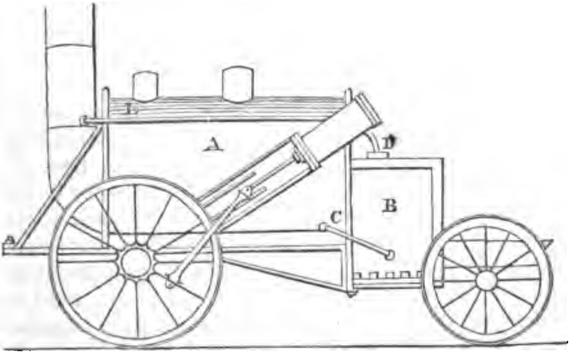

Fig. 63.

ance of the "Rocket" engine is illustrated in the preceding figure. It will be seen to differ in several particulars from the engines already described, particularly in the mode of generating the steam. A represents a cylindrical boiler with flat ends, six feet in length, and three feet four inches in diameter. To one end of the boiler is fixed a box, or furnace B, at the bottom of which are the bars of the grate; the box consists of a double case, having a space of about three inches between the two casings; this space is kept constantly filled with water. The boiler and furnace box are represented in profile in fig. 63, and in a transverse section, in fig. 64; the letters correspond with the same parts in both figures. A pipe C communicates from the lower part of the furnace case with the boiler, and supplies the latter with hot water; at the top of the case, a pipe D conveys the steam to the boiler. The upper half of the boiler is devoted to steam, the lower half is kept constantly supplied with water. The lower half of the boiler is traversed by 25 copper tubes, each of three inches in diameter, opening into the furnace-box at one extremity, and into the chimney at the other; these act as flues to convey the heat of the fire to the water in the boiler. The cylinders, one only of which is shown in the figure, were placed one on each side of the boiler; their action was confined to one pair of wheels, as represented above. The generation of the steam is effectually aided by the *draught of the chimney;* and this is materially increased by the escape of the steam into it from the cylinders by the pipes L, one of which is seen in the figure, the other being on the opposite side of the engine.

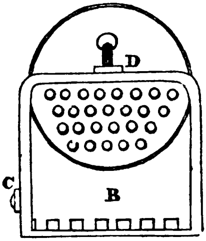

Fig. 64.

113. *Hackworth's "Sans Pareil" Engine.*—The next engine put upon trial was Mr. Hackworth's "Sans Pareil."

The weight of this machine, with its tender and load, was as follows:—

	Tons	cwt.	qrs.	lbs.
Engine	4	15	2	0
Tender, with water and fuel .	3	7	3	0
Three carriages, loaded with stones	10	19	3	0
Total weight . .	19	2	0	0

This engine, being above the stipulated weight for four wheels, was merely put upon trial, the results of which were to be made the subject of a further consideration. During the journey, the pump which supplies the boiler got out of order, and the experiment ended. The average performance of this engine was eleven tons, exclusive of the engine and tender, drawn at the rate of about fifteen miles per hour; the water evaporated, was nearly 150 gallons per hour; the coke consumed, 692 lbs. per hour. The general character of the "Sans Pareil" engine is given in the following figure.

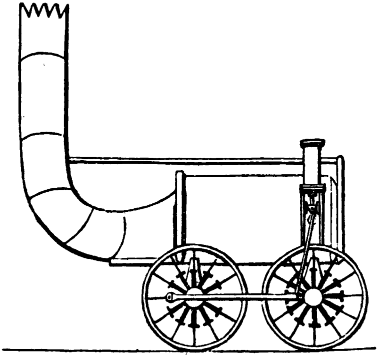

Fig. 65.

The boiler is cylindrical, and six feet in length, having one end flat, the other convex. The cylinders are placed vertically, one on each side of the boiler, and immediately over one pair of wheels; the other pair of wheels are connected with these by horizontal bars. The steam is generated in this engine on the same principle as in the "Rocket," viz. by the *draught of the chimney*, aided by the escape into it of the steam from the cylinders. A horizontal section of the boiler, flues, and chimney, is shown in the following figure. The boiler is traversed by a tube which is bent upon itself like the letter ⊃; the furnace D, and the chimney C, are thus placed at the same extremity of the boiler; at this extremity, the tube projects from the boiler to an extent of about three feet, where it terminates in the chimney C. The upper part of the tube is surrounded at its two extremities by a semicircular case, for the purposes of obtaining an increase of heating surface and of draught. The hot air passes in the direction of the arrows B B from the grate to the chimney.

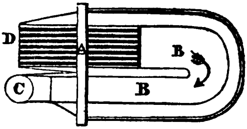

Fig. 66.

114. *Braithwaite and Erickson's "Novelty" Engine.*— The third engine was the "Novelty" of Messrs. Braithwaite and Erickson. It differed from the preceding engines, in having no tender, the water tank and fuel being conveyed on the engine itself. The weight of this machine, with its load, was as follows:—

	Tons	cwt.	qrs.	lbs.
Engine	3	1	0	0
Water, tank, and fuel . .	0	16	0	14
Two carriages, loaded with stones	6	17	0	0
Total weight . .	10	14	0	14

Some accidents occurred to the machinery of this engine during its journey, and it was consequently withdrawn, without having afforded sufficient trial to test its power. With the above load, it went at the rate of 17½ miles per hour; with the load detached, it conveyed passengers at the rate of 28 miles per hour. This engine is of light and elegant appearance; its construction and modification are represented in the two following figures; the former represents the engine in profile; the latter is a vertical section of it; the letters correspond to the same parts in both figures.

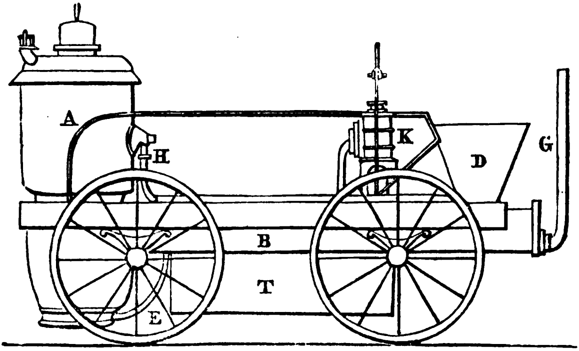

Fig. 67.

The principle by which the steam is here generated is different from that adopted in the preceding engines. A is the generator, or vessel in which the steam is raised; the lower part contains water, the upper part is filled with steam. Connected with this is a horizontal generator B, which being below the level of the water in A, is itself always full of water; the steam from B passes into A by the pipe H. The vertical generator A contains a tube C, fig. 68, which passes entirely from the top to the bottom; at its lower part it is enlarged, and receives the fire-grate F; the fuel is supplied from the top. The combustion of the fuel is effected by a strong blast of air produced by the bellows D, fig. 67, and conveyed to the fire-place through the tube E; the bellows are worked by the engine. The hot air from the fire traverses a tube *e*, which is twice bent within the horizontal generator, and then escapes into the air by the tube G. The steam cylinder K works one pair of the wheels by means of a *bell crank;*[*] the other pair are connected with these by chains. The action of this machinery will be readily understood by means of the vertical section, fig. 68.

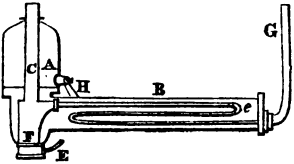

Fig. 68.

115. *Results of the foregoing Experiments.*—The "Rocket" engine having undergone the whole trial, and fulfilled all the conditions laid down by the directors, the prize of £500 was awarded to Mr. Robert Stephenson, for this engine. Let us now consider the improvements which were effected by means of the competition at Liverpool; these relate, first, to the *weight of the engine;* and, secondly, to its *increased evaporating power*. 1. Previously to these experiments, an engine, weighing with its tender ten tons and

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[*] The nature of the *single crank* has been frequently illustrated in the foregoing chapters; it can only be used upon the end of an axle. Fig. 69, represents the *bell crank;* it is obvious, from its construction, that it may be used upon any part of an axle; if placed between two wheels, it is capable of turning them both at once. Fig. 70, represents the *double bell crank*, which produces two alternate motions, reciprocating with each other. The vertical bars attached to the cranks are the connecting-rods, which are worked by the piston.

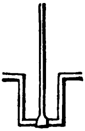

Fig. 69.

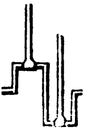

Fig. 70.

a half, was capable of drawing nineteen tons and a half, that is, a gross load of 30 tons, including the engine, at the rate of 10 miles an hour, on a level railway. But the "Rocket," weighing with its tender only seven tons and a half, drew nine tons and a half, that is, a gross load of 20 tons, including the engine, at the same speed. Such is the average estimate of the performances of the old and new engines. According to Mr. Scott Russell, the greatest loads drawn by the old locomotives were 28¼ tons weight, exclusive of engine and tender, at 10 miles an hour; while the "Rocket" drew 44 tons gross, exclusive also of engine and tender, at 14 miles an hour; or, in round numbers, the Rocket, only half the weight of the best drawing engines previously constructed, drew one-third more load at one-third more velocity. The result of this is important: the old engines had attained the maximum of weight practicable upon a rail; all further increase of power, therefore, resulting from increase of size was out of the question. In the new engine, a reduction of three tons weight was considered as so much additional weight capable of being added to the engine, and a proportionate increase of power was, consequently, expected. This anticipation has been amply verified. 2. An important result was also obtained in the economy of fuel. In the old engines, 18·34 lbs. of coke were required to evaporate a cubic foot of water; in the "Rocket," only 11·7 lbs. were required to produce a similar effect. But the advantage of an engine of light weight and small power is not to be estimated by the reduced consumption of fuel, for, by the "Rocket" itself, when travelling at a rapid pace, and drawing only three times its weight of carriages, the expense of fuel per ton per mile is greater than in the old engines. The real advantage of the new engine is found in the *increased evaporating power* of which it is capable; the number of cubic feet of water evaporated per hour by the "Rocket" was 18·24, whereas by the old engines the number was only 15·92. The increased evaporating power of the new engine was owing to the number of tubes introduced into the boiler, presenting a large area of heating surface to the water. Thus the "Rocket" engine, weighing only 4¼ tons, had an extent of evaporating surface, three times and a half greater than the old engines, which weighed upwards of 7 tons. The great object to be attained in subsequent improvements was, therefore, to increase the evaporating surface; and the additional weight which the new engines were capable of receiving, afforded a valuable means of securing this object.

116. *Further Improvements in the Locomotive Engine.*—The principal improvements introduced into the locomotive engine, soon after the date of the Liverpool experiments, were of three kinds. 1. The *cylinders* of the "Rocket" were placed *outside* the engine; their temperature was consequently reduced by exposure to the atmosphere, and a proportionate amount of heat was lost by the condensation of steam thus produced. In engines subsequently constructed, the cylinders were accordingly placed *inside* the casing upon which the chimney rested; they were thus exposed to the heated air as it escaped from the flue tubes within the boiler to the chimney, and maintained at the temperature of this air, by which means condensation was prevented. 2. A second improvement consisted in *increasing the evaporating surface.* The additional weight which the new engines were capable of receiving, was devoted to the enlargement of the boiler, and to an increased number of flue tubes of smaller diameter than those of the "Rocket." In this engine, the number of these tubes was 25, their diameter being three inches; the surface thus exposed to the heated air was 113 square feet. In engines of later construction, the number of tubes has been variously increased: the Meteor had 88 of two inches diameter; the Comet, Arrow, and Dart, 90 of the same diameter; the Northumbrian, 132 of about an inch and a half diameter; and in an engine built by Mr. Robert Stephenson for the Grand Junction Railway, the number of tubes amounted to 169. The effect of this increase of evaporating surface was immediately

perceived in the increase of power. The quick trains soon attained a rate of velocity equal to twenty miles per hour, and this rate has since been increased. In the "Planet," the ninth engine built by Mr. Stephenson for the Liverpool and Manchester Railway, the number of tubes was 129, of about an inch and a half diameter; the surface of these tubes was 370 feet. On December 4th, 1830, this engine conveyed passengers and goods, amounting to a gross load of 80 tons, exclusive of the engine, from Liverpool to Manchester, in little more than 2½ hours, with new machinery, and against an adverse wind; the maximum speed was 15½ miles per hour. 3. In the "Rocket" engine, the *cranks* were fixed to the wheels, that is, to the two extremities of the axle, at the points of greatest distance from the centre of resistance. The inequality with which the impelling power would act upon these points, owing to the alternate motions of the connecting-rods, would necessarily produce an injurious strain upon the machinery. To obviate this difficulty, the cranks were subsequently removed from the wheels, and placed upon the axle towards its centre; and they were so adjusted, that while one of them is horizontal, the other is vertical, and *vice versâ;* by this means, a continual rotation of the wheels is effected, one of the cranks being continually subject to the energetic action of the cylinder and piston-rod.

117. *Mr. Bury's Engines.*—Mr. Edward Bury, of Liverpool, has contributed to the improvement of the locomotive engine. The principal features in his engines, are *horizontal cylinders*, and *cranked axles.* "The first engine made by Mr. Bury was the 'Dreadnought,' which was started on the Liverpool and Manchester Railway, March 12, 1830. *She had six wheels, and was much objected to on that account.**

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* This observation, made by a writer of considerable experience and ability, previously to the present outcry upon the subject of *four* and *six-wheeled* engines, is entitled to attentive consideration. Opinions are divided upon the comparative merits of the two classes

The next was the 'Liverpool;' this was the original engine made by him with horizontal cylinders and cranked axles. She was placed on the Liverpool and Manchester Railway, on July 22, 1830, and had an 18-inch stroke, two pair of six-feet coupled wheels, and 12-inch cylinders. The great danger in cranked axles is from their breaking, which, with four-wheeled engines, might occasion considerable damage. They have been repeatedly broken; but this has not happened fairly to one of Mr. Bury's manufacture; only two have been broken, and in both cases from bad welding. One of these, the engine No. 14 on the London and Birmingham Railway, was discovered to have been actually running for some time with a broken axle, without its being found out; this arises from the eccentrics being keyed on to the weakest parts of the axle, and thus forming a protection against accidents. The above axle had only two-thirds of its section soundly welded when sent from the manufactory. Mr. Bury's engines are now all made with cranked axles and *four wheels*, the goods' engines being coupled, and the passengers' not. We attribute the success of his axles in some measure to the mode of constructing the framing, and to his bearings being inside the wheels, as any shock from obstructions on the road is thus thrown upon the bearings, and not on the crank; the framing is made with great breadth and but little depth, in order to resist lateral shocks; whereas most other makers' have great depth and but little width, which would afford the most powerful resistance to vertical shocks, but, in conjunction with the bearings being outside the wheels, would throw all the lateral ones on the crank. Many broken axles, however, have been produced by gross neglect in their manufacture. We

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of engines. While these sheets are passing through the press, Mr. Herapath, the spirited Editor of the *Railway Magazine*, is engaged in making researches on this point, and has already travelled over many of the lines for the purpose of gaining satisfactory information. A complete report of the results of his labours may be shortly expected.

have seen one which had been welded together, and there was not a junction of a tenth of an inch in the iron, all round; the whole central part being perfectly black, with not the smallest sign of welding. Mr. Bury cuts his out of the solid iron, and only welds the part joining the cranks to set them at right angles. Some makers twist the axles for this purpose."—*Scott Russell on Steam*, &c. 1841.

118. *Dr. Lardner's Experiments.*—The rapid progress of improvement made at this period in the locomotive engine was abundantly testified by its increased power, and the economy of fuel. In the spring of the year 1832, some experiments were made on the Manchester Railway by Dr. Lardner; the results are thus stated by himself:—"On May 5, 1832, the engine *Victory* (weight 8 tons, 2 cwt., of which 5 tons, 4 cwt. are on the working wheels—cylinder 11 inches —stroke 16 inches diameter—working wheels 5 feet diameter) drew from Liverpool to Manchester (30 miles) in 1 hour, 34 minutes, 75 seconds, twenty loaded waggons, weighing gross 92 tons, 19 cwt. 1 quarter; consumption of coke 929 lbs. net; was assisted up Rainhill plane 1½ mile by the Samson. She spent 10 minutes in watering and oiling half way. The fire-place was filled with coke at starting (not weighed), and was again filled with coke on arriving at Manchester (weighed); the coke used in getting up the steam not included in the above estimate.

Speed on the level . . .	18 miles an hour.
Fall of 4 feet in a mile . .	21·50
——— 6 in do. . . .	25·50
Rise of 8 feet in do. . .	17·63
Level sheltered from wind .	20

"N.B.—Moderate wind direct a-head; slipped on Chat-moss, and retarded two or three minutes.

"On the 8th of May, the same engine drew 20 waggons, weight gross 90 tons, 7 cwt. 2 quarters, to Manchester, in 1 hour and 41 minutes; stopped to water, &c., 11 minutes half way, not included in the above; consumption of coke 1040 lbs. under the same conditions as first experiment.

Speed on the level . .	17·78 miles an hour.
Fall of 4 feet in a mile .	22
——— 6 feet do. . .	22·25
Rise of 8 feet do. . .	15

"N.B.—High wind a-head; connecting-rod worked hot, being keyed too tight; on arriving at Manchester, pistons found so loose in cylinders that steam blew through.

"On the 29th of May, the engine called the *Samson* (weighing 10 tons, 2 cwt. with 14-inch cylinders, and 16-inch stroke; wheels 4 feet 6 inches diameter, both pair being worked by the engine, steam 50lbs. pressure, 130 tubes,) was attached to, with 50 waggons laden with merchandize, net weight 150 tons. The engine with this load travelled from Liverpool to Manchester, 30 miles, in 2 hours and 40 minutes, exclusive of delays upon the road for watering, &c., being at the rate of nearly 12 miles an hour. The speed varied according to the inclinations of the road. Upon a level it was 12 miles an hour; upon a descent of 6 feet in a mile, it was 16 miles an hour; upon a rise of 8 feet in a mile, it was about 9 miles an hour. The weather was calm, the rails very wet, but the wheels did not slip, even in the slowest speed, except at starting, the rails being at that place soiled and greasy with the slime and dirt to which they are always exposed at the stations. The coke consumed in this journey, exclusive of what was used in getting up the steam, was 1762 lbs., being at the rate of a quarter of a pound per ton per mile."

119. *Most recent Locomotive Engine.*—Within the few last years, numerous improvements have been introduced into the construction of the locomotive engine. The various and minute details connected with this subject are fully explained, and illustrated by a series of excellent plates, in Tredgold's work on the Steam Engine. The plates exhibit a patent locomotive engine, made by Messrs. R. Stephenson and Co., in 1836, for the London and Birmingham Railway; its original cost was about £1400; it has drawn a load up an inclined plane equivalent to 220 tons gross weight upon

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a level, including engine and tender, at a velocity of 14 miles an hour, with the steam at the usual pressure of 50 lbs. on the square inch within the boiler; the force required for this task, is about 2050 lbs. moving at that velocity, which is equal to 77 horse power. This engine has drawn 40 tons at 35 miles an hour, which is equivalent to 40 horse power. It is capable of evaporating 77 cubic feet of water per hour, or eight gallons in a minute; the old locomotives could evaporate only 16 cubic feet per hour. Dr. Lardner states, that this amount of evaporation is inferior to that which he has himself ascertained to be produced by engines in regular operation on some of the northern railways; that the ordinary evaporating powers of the engines on the Grand Junction Railway, varied, in 1838, from 80 to 85 cubic feet per hour; and that in engines of much greater dimensions, as those on the Great Western Railway, 200 cubic feet of water have been evaporated per hour. The consumption of fuel per mile for every ton of the gross load, in Stephenson's engine, is about a quarter of a pound, and that of the water is rather less than a quarter of a gallon: the consumption being proportionally greater with a light load; with a full load, it is a cubic foot per hour for each horse power.

120. *General Description of a modern Locomotive Engine.*—The general construction and management of a modern locomotive engine, and the relation of its parts to each other, are now to be described. The order of description will comprise an account, 1st, of the boiler and its appendages; 2d, of the cylinders and their appendages; and 3d, of the general method of working the engine. In the following engraving, fig. 1 represents an entire engine; fig. 2, a vertical section of the same through its entire length; fig. 3, an end view of the interior of the boiler; and fig. 4, one of the cylinders and its appendages, separated from the engine. These figures are copied from the last edition of Wood's *Treatise on Railroads.*

(1.) *The Boiler, and its Appendages.*—In figs. 1 and 2, the *boiler*, which constitutes the main feature of the engine, is represented at *a a' b b'*; it is of a cylindrical form, about eight feet in length, and three in diameter; it is formed of wrought-iron plates, which lap over each other, and are joined together by iron rivets. A front view of the end of the boiler is seen at *a'' b''* in fig. 3. The boiler is traversed by numerous *tubes*, which are shown in their horizontal position at *k k* in fig. 2; their orifices are seen in the end view at *k* in fig. 3. The tubes are inserted into perforations of the plates at each extremity of the boiler. To counteract the pressure of the steam against these plates, several stays *o o* are fastened to the chimney end of the boiler, and to the exterior surface of the fire-box chamber, as seen in fig. 2.

(2.) At the *right extremity of the boiler*, a chamber *a c d d'* is represented in the end view, fig. 3; its upper part is of a hemispherical form, and is of a somewhat larger diameter than the boiler; a section of this chamber in its horizontal position is shown by the same letters in fig. 2; its exterior form is seen in fig. 1. Within the chamber is fixed the *fire-box*, *e e' f f'*; this is nearly of a square form; below, it is riveted to the chamber at *d d'*; the grate bars are seen at *g g'*, and the door of the fire-box at *h*; above, the fire-box is secured against the pressure of the steam by iron bars, *i i i i i*, which are fastened by bolts screwed on the under side, and keyed on the upper side, as represented in figs. 2 and 3; the sides of the fire-box are also secured against the pressure of the steam by means of cross bolts, which are represented, in the same figures, as fastened to the fire-box and the chamber. From the above description, it will be seen that the fire-box is almost entirely surrounded by the water of the boiler.

(3.) At the *left extremity of the boiler*, fig. 2, is a chamber, or *smoke-box*, *l a' l' l''*, of similar form to that already described. This chamber terminates above in the chimney *m*, and thus affords a means of escape for the smoke after it has traversed the tubes within the boiler. The chamber is opened, for the purpose of being cleaned, by a door at *n*. The cylinders and steam tubes occupy this chamber.

(4.) The *upper part of the boiler* presents several objects which deserve notice; these are seen entire in fig. 1, and in section in fig. 2. Commencing at the furnace end of the boiler, the first object is the *steam whistle* at *x*, a contrivance for producing a shrill sound, as a prelude to starting, or a warning on the road. It consists of a pipe, which is fastened into the top of the boiler, and may be opened or closed by a cock, the handle of which is seen in fig. 1; when open, the steam from the boiler rushes through the tube into the lower cup just above the cock; here, it passes through some apertures in a metallic plate which is placed horizontally within the lower cup, and impinges with great force against the thin edge of the upper cup, producing its characteristic sound. The next object is a large opening *p*, called the *man-hole*, from its office of admitting a man into the interior of the boiler, for the purpose of cleaning or repairing it; when the engine is in use, the man-hole is closed by means of an iron plate, fastened steam-tight, upon a tube raised a little above the surface of the boiler. At *q q'* are two openings for the safety valves. The safety valve *q*, nearest to the man-hole, is under the management of the engine driver; it is furnished with a handle, which is attached to some apparatus on the other side of the engine, for the purpose of indicating the pressure of the steam. The other safety valve *q'* is covered up, and placed out of the control of the engine driver. The load on the latter valve is less than that on the former, so that the steam escapes from the latter valve first, and warns the driver to reduce the intensity of the fire; this is effected by means of a fan, or damper, placed within the chimney, and regulated by a rod *w w*, seen in fig. 1. The last object to be noticed on the top of the boiler is the chamber B, into which the steam from the boiler rises, previously to its passing into the steam tubes in its way to the cylinder. This chamber will be noticed more particularly in a subsequent paragraph.

(5.) *The Cylinders, and their Appendages.*—The cylinders are placed horizontally, at the chimney end of the boiler, one on each side of the engine. One of the cylinders is represented, *in situ*, at A; the other is seen separately in fig. 4; they are both placed within the chamber into which the hot air enters from the tubes of the boiler, and are therefore maintained at a high temperature. The pistons are marked by the figures 5 and 6; the piston-rods 5, 5, and 6, 6, work steam-tight through the stuffing-boxes 8, 8; they are attached at their further extremities to the connecting-rods 5, 9, and 6, 10, which work the cranks upon the axle of the engine; the crank connected with the cylinder A is represented in the same line as the piston-rod, while that of the cylinder D is at right angles to it. The steam passages leading to the upper and lower parts of the cylinder A, are seen at *a a'*; those of cylinder D, at *c c'*; in both figures, *r* is the steam chamber, into which the steam issues from the boiler, previously to its being admitted into the cylinder by the action of the slide *e e'*; the passage by which the steam is discharged from the cylinder, in both figures, is seen at *z*.

(6.) The *Regulator, and Steam Pipes.*—In fig. 2, the steam chamber *r* is supplied with steam from the boiler by the tube S, which is carried through the boiler, and extends almost to the top of the chamber B. The object of this chamber will now be readily understood. To prevent any water from passing together with the steam into the cylinders,* owing to the agitation of the water which occurs in moveable engines, the orifice of the main steam tube is placed as far out of the reach of the water as possible; by this means, the steam alone rushes, in the direction of the arrows, from the boiler into the cylinder, while the water merely dashes against the outside of the tube, and falls back into the boiler. The *regulator*, by which the supply of steam is increased or diminished, is placed at D, and communicates from the tube C in the chamber of the boiler, to the tube S in the chamber which contains the cylinders.

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* This mixture of water and steam, when carried into the cylinders by the cause above mentioned, is technically called *priming*.

At this point D there are two pipes branching from the main tube C, one for each cylinder; in fig. 2, only one of these pipes is seen, the other being placed behind it. A complete view of this apparatus is shown in the adjoined figure. C represents a transverse section of the main tube, leading from the chamber B, and S S are the two steam pipes leading to the two cylinders. The orifices of these pipes are guarded by two sliding discs, marked 1, 1, which move backward and forward, and thus open and close the two orifices, alternately; the discs are attached to a horizontal rod, 2, 2', represented in fig. 2, which passes through the boiler, and is turned by a handle shown at 4; a sliding joint at 2', and a spiral screw at 3', are adapted to this rod, in order to obviate any inconvenience arising from its expansion and contraction, produced by variations of the temperature within the boiler.

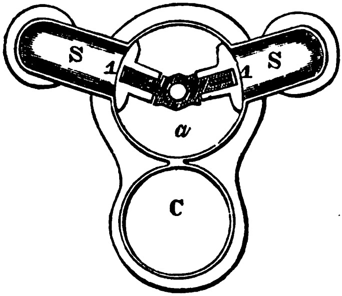

Fig. 71.

(7.) *Draught of Chimney.*—By means of the regulator and steam pipes, the cylinders are supplied with steam. We are now to consider by what means the steam is discharged from the cylinders. The height of the chimney *m* being insufficient to produce the draught required for the effective combustion of the fuel, and production of steam for the due working of a locomotive engine, the steam from the cylinders is discharged into the chimney, for the purpose of producing an efficient draught. In fig. 2, the orifice of the discharging tube is seen at *t*, from which the steam from the cylinders issues upward in the direction of the arrow. In the annexed figure, this part of the machinery is exhibited more completely. As there are two pipes leading *to* the cylinders, described in the preceding paragraph, there are also two pipes leading *from* the cylinders into the chimney. These pipes are shown at *v v;* they gradually converge, and terminate in the single pipe C, called the *blast pipe*, which opens immediately into the chimney, as represented also in fig. 2.

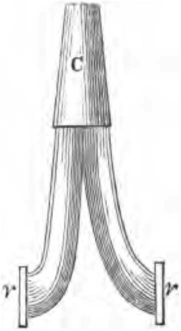

Fig. 72.

(8.) *Working of the Engine.*—The general construction of the boiler and the cylinders, with their apparatus, having been described, the general working of the engine will be readily understood. This depends on the mode of admitting steam into the cylinders, the reciprocating motions of the slide, and the action of the piston-rod and crank. 1. The *admission of steam into the cylinders* is regulated by means of the slide *e e'*, which moves upon smooth surfaces on the side of the cylinder, as already explained at page 112. In fig. 2, the slide is so placed that the steam rushes into the upper part of the cylinder through the passage *a'*, while the steam from the lower part of the cylinder rushes through the passage *a* into the discharging pipe *z*, which terminates in the blast pipe *t*. In fig. 4, the position of the slide is altered: the steam enters the lower part of the cylinder at *c*, while the steam from the upper part escapes through *c'* into the discharging pipe *z*, which also terminates in the blast pipe. 2. The *reciprocating action of the slides* is effected by means of *eccentrics*, placed upon the axle of the driving wheels. The reader is particularly referred to the description of this mechanism already given at page 120; he will then understand how the rotatory motion of the axle produces a horizontal motion of the slide. Thus, in fig. 4, the wheel H, encircled by its ring L, revolves eccentrically around the axle; the wheel is attached at L to a horizontal rod, which is connected with the cross bar M N, fixed at R, and thus communicates, at every revolution of the axle, a backward and forward motion to the slide, by means of its rod P, so as to transmit the steam to, and cut it off from, the top and bottom of the cylinder, alternately. A similar apparatus is seen in fig. 2, in which H I represents the eccentric, S T the cross bar, and R the fixed point on which the cross bar moves. The beneficial action of the slide in regulating the supply of steam is obvious from its being continually in motion, so as to commence closing the steam passages immediately after having fully opened them, and thus preventing any jar which might be produced by a too free admission of steam into the cylinders. 3. The general *action of the piston-rod and crank* has been explained at page 55; the machinery by which the rectilinear motion of the former is adjusted to the rotatory motion of the latter, has been described at page 52. It will be sufficient, in the present case, to state, that the parallelism of the piston-rod is effected by means of parallel sliding plates,* which enter into the mechanism of the joints 5 and 6, where the piston-rods are attached to the connecting-rods of the cranks. The axle is furnished with a pair of bell cranks, sections of which are seen in figs. 2 and 4; in the former, the crank is horizontal, in the latter it is vertical, and thus a continuity of action is produced.

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* The description of this machinery involves some intricate details. The curious reader may find these in the account of Stephenson's patent locomotive engine, given in the work of Tredgold, p. 434.

(9.) *Reversing Eccentrics.*—It is necessary for a locomotive engine to be enabled to travel backward as well as forward; but with the reversed motion of the engine, the position of the eccentrics must be *reversed*. This may be effected in two ways. 1. In cases in which each cylinder is provided with only one eccentric, this is placed loose upon the axle, so as to admit of having its position, with reference to the crank, reversed, whenever it is necessary to reverse the motion of the engine. 2. It is more usual to employ two eccentrics for each cylinder, the one for working the slide in the forward motion, the other in the backward motion, of the engine; when the motion of the engine is to be reversed, it is necessary that one pair of eccentrics be thrown out of gear, while the other pair is put in gear. This is effected by means of a hand lever, which is turned by the driver of the engine.

121. *Mr. Hall's Smoke Consumer.*—Mr. Samuel Hall, of Basford, near Nottingham, has recently introduced a method of consuming the smoke and inflammable gases, simultaneously with the other component parts of coal, by which means considerable economy is effected by the use of coal instead of the expensive article coke. Taking the cost of coal and coke respectively on the Midland Counties' Railway as a ground of calculation, it is stated that £100 worth of coal will evaporate as much water, and propel a train as many miles, as £235 worth of coke. The apparatus by which this economy of fuel is effected, has been in operation for several months in the "Bee" locomotive engine, on the above railway, and has more recently been adapted to many stationary engines in our manufacturing towns. The testimony of Mr. Herapath respecting the success of this invention in the case of the "Bee" engine, is most satisfactory. "I could not," he observes, "with my utmost attention, discover any difference between the colour of the emissions from the chimney and the safety valve, though nothing but pure coal was used, and not the slightest taint of the atmosphere was perceptible to me." (*Railway Mag.* Dec. 11,

1841.) The result of an experiment of the same engine, lately made by a party including several Directors and Engineers of various railways, was equally decisive: not only was there not a "*particle* of smoke" produced while the engines were in operation, but the smoke was equally consumed when they were in a state of rest. (*Railway Times*, Dec. 11, 1841.) This invention consists in the introduction by side and front tubes of a certain quantity of atmospheric air of a high temperature into the fire-box; this air passes over the fire from one end to the other, and effects the combustion of any unignited inflammable gases, carbon, and other combustible matters, as they are generated and liberated from the fuel, and before they arrive in the form of smoke to the chimney, or perhaps even to the flues leading to the chimney.

122. *Experiment of the "Bee" Engine.*—In a report made by Mr. Marshall, the engineer of the North Midland Railway, on the subject of the "Bee," the following statements occur:—"The patent smoke-consuming apparatus consists of sixteen tubes in the lower three rows of the boiler, which are prolonged by moveable tubes through the smoke-box door, and also four tubes of the same size are inserted at each side of the fire-box at the same level, making in all twenty-four tubes of 1¼ inch diameter, for supplying a stream of fresh air over the fire at the level of the lower boiler tubes. To maintain a constant draught in these air tubes when the engine is standing, a small steam pipe is led into the blast pipe, which throws a jet of steam when the engine is not working."

In an experiment of this engine, made last October, Mr. Marshall reports as follows:—"Steam well up; pressure on valve altered from 55lbs. to 60lbs. on the inch, as in North Midland engines; *smoke consumed completely* with the extra steam blast whilst standing, leaving scarcely any appearance but the steam out of the chimney." Again:—"*Smoke consumed completely*, whilst running with the ordinary blast alone, leaving only a faint tint, except rather at starting, from filling up the fire, the steam well kept and fire good in the trip." Once more:—"*Smoke consumed completely* in both trips, leaving no colour in the steam that would be observed, and the supply of steam abundant throughout, being always blowing at the safety valve, with the use of the extra blast only, whilst the steam was shut off from the cylinders."

123. *Other Improvements of Mr. Hall.*—1. The improvement, briefly noticed in the preceding paragraphs, is at once simple and inexpensive. Instead of supplying the fire-box with atmospheric air by tubes or flues outside the boiler, some of the tubes already existing *within* the boiler are devoted to this purpose, being merely continued on by means of moveable tubes, to the door of the smoke-box, where they are open to the atmospheric air. In the case of locomotive engines, a further supply of common air is admitted through smaller tubes inserted into the fire-box, and also by perforations made in the door of the fire-box. The temperature of the latter supply of air is, of course, considerably below that of the former; but, the latter quantity being much smaller, no injurious effect is produced in the temperature of the total supply of air. 2. It is obvious that, while the engine is in motion, with its air tubes open to the atmosphere in the front of the smoke-box, there will be a considerable draught of air through the engine; but that, when the engine stops, and there is no discharge of steam through the blast pipe, the draught will be discontinued, and dense volumes of unconsumed smoke will issue from the chimney. To prevent this, Mr. Hall adapts a pipe and a valve to the boiler, so as to *transmit a portion of steam up the chimney, when the engine is at rest*, and thus to produce a draught of air in the same way as is effected by the steam which escapes through the exhausting pipes of the engine when in activity. 3. Another valuable improvement is that of *condensing all the waste steam* by means of the water in the tender, when the engine is at rest. Instead of injecting the steam immediately into the water, and thus producing in-

jurious shocks to the tender, Mr. Hall introduces a series of pipes[*] immersed in water into the tender, and causes the steam to pass smoothly through them, by which means it is condensed, and afterwards returned, in the form of water at a high temperature, to the boiler. By following out this method, all the steam at present discharged, during the inactivity of the engine, by the safety valve, would be saved and devoted to useful purposes. 4. Another, and most interesting part of the invention, is a contrivance for *making every tube within the boiler take its due share of heat from the fire, instead of the upper tubes taking more than the lower ones*, owing to the tendency of the heat to ascend to the upper part of the smoke-box in its progress to the chimney. This improvement consists of a metallic plate, bent into the form of an arch, and introduced into the smoke-box, so as to leave a space between the plate and the sides and top of the smoke-box. This plate is perforated by a great number of small holes, the aggregate area of which is equal at least to the area of the chimney; Mr. Hall states that he would prefer having their area equal to double that of the chimney, or even more, so as to give a free passage of all gaseous matters through them into the space between the plate and the sides and top of the smoke-box, on their progress to the chimney. The plate is called a *distributing plate*, from its effect in distributing the heat equally through all the tubes of the boiler. This plate has the further advantage of preventing the passage of any portions of ignited fuel from the smoke-box to the chimney. 5. Among the collateral advantages arising from the better combustion of fuel and smoke, two may be noticed as materially conducive to the comfort of the *passenger:* the offensive odour arising from decomposition of the steam during the stoppage of the engine, and the escape of particles of ignited fuel from the chimney, are both obviated.

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[*] This series of pipes constitutes the *patent condenser* of Mr. Hall, an apparatus which will be fully described and illustrated in the following chapter.

124. *Mr. R. Stephenson's new Engine.*—Mr. Robert Stephenson has taken out a patent for a new engine, in which three important alterations are introduced. 1. The length of the *boiler*, and consequently the extent of heating surface, are increased about 50 per cent., the tubes being 12 feet long, instead of from 8 to 9; by this means, the patentee expects to be enabled to reduce the intense heat of the air in the smoke-box, so destructive to the tubes in that part. The fire-box is reduced 25 per cent. The result of these two changes he considers will be a considerable saving of fuel. A small pair of trailing wheels are placed close *before* the fire-box, instead of behind them, as in other engines with shorter boilers; the driving wheels are in the centre, as in other engines, their axles being thus under the centre of gravity of the engine; the leading wheels are placed just behind the smoke-box, as in a four-wheel engine. Indeed, this engine, with regard to the relative positions of the fore and hind wheels, in respect of the fire and smoke boxes, is a four-wheel engine extended from 6 to 11 feet. 2. The *valves* are placed at the sides of the cylinders, instead of at the top; the consequence of which is a direct connexion between the eccentrics and the valves, a saving of all the levers, with their cost of construction, their wear and tear, and a more tight and certain action of the valves. 3. The *pumps* are worked with a shorter stroke, from the reversing eccentrics, by which a slower motion of the pumps is obtained, and the wear and tear of them is expected to be diminished. The anticipated results of these alterations are, economy in fuel, and diminished wear and tear of the engines.

OF RAILS AND RAILROADS.

125. *Materials and Form of Rails.*—The object of a railroad is to provide hard, smooth, and unchanging surfaces for the wheels of carriages to roll upon. These

surfaces consist of two parallel rows of *rails*, or bars, of a suitable material and form, raised a little above the general level of the ground, and presenting upward a smooth and even surface. The rails are placed neatly end to end, and secured by fastenings to blocks of wood or stone, called *sleepers*, which are embedded in the earth at intervals of about three feet. 1. The earliest railway employed in this country was constructed of *wood*. In 1676, coals were conveyed, near Newcastle-upon-Tyne, from the mines to the banks of the river, "by laying rails of timber exactly straight and parallel; and bulky carts were made with four rollers fitting those rails, whereby the carriage was made so easy, that one horse could draw four or five chaldrons of coals."* In the wooden railways, the upper surface of the rail being convex, a projecting edge, or *flange*, which dips on the outside, was attached to one side of the circumference of the wheels, in order to keep them upon the rails. 2. About a hundred years afterwards, Mr. Curr constructed a railway of *cast iron* at the Sheffield colliery; it was called the "plate rail." The rails consisted of flat bars, having an upright ledge for retaining the wheels on the line, and nailed down to wooden sleepers. In the plate railway, the carriages were kept upon the lines, by means of the ledge of the rail, which formed a substitute for the flange of the wheels; these were, accordingly, made flat and of less breadth. 3. In 1789, Mr. Jessop introduced a form of railway, termed the "edge rail," in which the edge of the rail was presented upward, and the wheels of the carriages were flanged, as in the case of the wooden railway. The following figure represents a side view of a common cast-iron edge railway. S represents the *sleepers*, consisting of large blocks of stone with a broad base, which are previously placed in the ground at a proper level. To the sleepers are fixed pieces of cast iron, C, called *chairs;* these have a flat base, from which two upright ledges are cast as far apart as the breadth of the rail, thus forming a cavity into which the ends of the rails, R, are fastened together by means of iron pins. 4. At the beginning of the present century, rails of *malleable iron* were first introduced; but owing to their expensiveness, they were little used until 1820, when a patent was obtained by Mr. Birkinshaw for manufacturing or rolling rails of malleable iron, which should combine the same bearing surface as the cast-iron rail, with the most improved form for ensuring strength; in the present day, malleable iron is exclusively used in all public lines of railway. The supports, or sleepers, are now usually constructed of wood, this material being found to yield more readily than stone to the rolling of the wheels, and thus to obviate the injurious effects of jolting on the carriages. On the Great Western Railway, between London and Bristol, a plan has been adopted of placing rails, having parallel surfaces, upon longitudinal beams of timber, which are united at intervals by transverse bars. 5. Rails of malleable iron are of two *forms*. One of these is the *fish-bellied* or *elliptical rail;* in this form, each rail is of about twelve feet in length, and six inches in depth at the two extremities, from which it gradually deepens downward into the characteristic form just mentioned, and which is seen in fig. 73. The other is the *parallel rail;* in this form the lower surface, instead of swelling out like that of the preceding variety, is parallel to the upper surface. There is considerable difference of opinion as to the comparative merits of these two forms of rail; both kinds have been laid down on the London and Birmingham Railway.

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* Roger North's *Life of Lord Keeper North.*

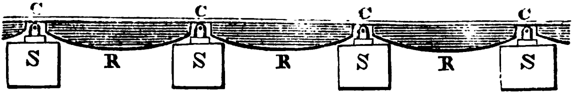

Fig. 73.

126. *Of the Construction of Railroads.*—The expense of constructing a railroad, simple as it may appear when finished, is exceedingly great. In the first place, the land through which the line is to pass, must frequently be purchased at an exorbitant price; and the preliminary expenses of legal process and of procuring an act of parliament to sanction the line, sometimes amount to as much as £2000 per mile. If the proposed line be carried through a tract of country presenting great inequalities of surface, the expenses of excavating, embanking, tunnelling, &c., become enormous; an entire charge of £30,000 per mile is considered a moderate expenditure in the construction of railroads in this country. 1. The *formation level* of a proposed line being determined, all the portions above this level must be cut away, or *excavated,* while all the space below it must be filled up, or *embanked.* It is, of course, desirable that the quantity of material obtained by excavating should be equal, as near as may be, to the quantity required for embanking; and that the distances between the places of these two operations should not be great. In cases in which these advantages cannot be secured, additional expense is necessarily entailed; where the excavated materials are insufficient for the embankments, the deficiency must be made up from other land by what is termed *side cutting;* where the excavated materials exceed those required for embankment, the surplus is thrown aside, or *laid to spoil;* and where the distance is too great between the excavation and the embankment, either or both of these inconveniences may occur. 2. In America and in Belgium the lines generally consist of only *one track;* in Great Britain there are always *two tracks,* in order to accommodate trains going in opposite directions. 3. *The width between the rails* was, in the early period of railways, determined by the legislature at four feet eight inches and a half, and this is the width observed on most of our principal lines. In 1836, this rule was suspended, and the width on the Great Western Railway is seven feet. The policy of departing from a *standard*

width seems questionable, when the communications likely to occur between the great lines are considered, for it is obvious that the engines and carriages must be changed wherever the width of two lines varies, and that much inconvenience will be occasioned by loss of time and other circumstances. The breadth of the bearing part of the rails is generally two inches and a half. 4. *The width between the two tracks* on the Liverpool and Manchester Railway is the same as that between the rails, viz. four feet eight inches and a half. On the London and Birmingham Railway, it is six feet. According to Mr. Wood, the latter width is preferable upon great lines of railway; but experience has shown that no great inconvenience is felt upon lines of the former width. 5. *The width between the rails and the edge of the embankment* must be sufficient to ensure the stability of the sleepers and of the rails; a width of four feet is found to be perfectly sufficient for these purposes. Mr. Wood observes: "On approaching a narrow embankment, at a rapid rate, the general impression is, that the engine will *run* over the side of the embankment, and *drag* the train of carriages over it. Nothing can be more fallacious; for, if the engine were, by any accident, to run off the rails, it would not *drag* the carriages after it. If it go over at all, the carriages will *push* the engine, but the engine will not *drag* the carriages over, for this very simple reason: if the engine do run, or be thrown off the rails, a diminution of its speed immediately takes place; and, there being no such check to the carriages, their inertia carries them forward against the engine, *pushing* it on until the whole train is stopped. In approaching the question, we must, therefore, consider it with reference to that mode of action; and, likewise, with reference to the immense tangential force inherent in an engine and train of carriages moving at so rapid a rate." According to this experienced writer, we have the width of the excavations at the formation level, including the width for drainage of water on each side of the railway, in the following proportions:—

Two lines of railway, including rails .	10 ft.	2 in.
Width between the two lines . .	6	0
Width on the outside of rails . .	10	0
Width required for the slopes . .	4	0
Width for the drainage . . .	3	0
	33	2

127. *Of Turn-outs, or Passing Places.*—In *public* lines of railway, on which two trains may be travelling in the same direction, and at unequal speed, it is necessary to provide a means by which the slower train may *turn out* of one track, and cross over to the other, in order to allow the faster train to pass it. This is effected by means of a moveable rail, or *switch*, placed at the point where the turn-out track branches from the main-track, and passing obliquely across the line of rails, at such an angle as to obviate any considerable shock to the carriages on entering upon it, to prevent the wheels from running off the rails, or from twisting the frame of the carriages. The *angle* should depend upon the rate of speed at which the train is travelling. Upon the private colliery railways, where the rate of speed is not more than eight miles an hour, the angle is generally between 6° and 7°; but upon public lines of railway, where the speed is great, a less angle than 2°, or 2½°, should not be adopted (Wood). The moveable rail is placed in its proper position by an attendant; hence, it is important to have as few passing places as possible. In *private* lines of railway, in which there is only one main track throughout the entire length, short intervals of double tracks are laid down, with proper turn-outs to admit of carriages passing each other in opposite directions.

128. *Of Tunnels.*—The subject of tunnels will be here noticed merely with reference to certain objections made, in the year 1836, by men of reputation, before Committees of the House of Commons, as to their supposed injurious effects upon the health of passengers, owing to the alleged diffi-

culty of *ventilating* them. On this subject Dr. Arnott observes: "These parties thought they saw six great dangers to health in the tunnels:—viz. 1. *The temperature.*—Yet this in tunnels is always the medium temperature of the climate, equally removed from the two hurtful extremes of heat and cold, and differs little from the natural atmospheric temperature of a great majority of days in the year. And in the warmest summer noon, a person entering a tunnel for the usual minute or two of the passage, is less tried, than a person in winter crossing a staircase from one warmed room to another; and much less, than one who follows the almost universal practice of going to bed in a room without a fire. 2. *Impurity of air from smoke.*—Yet the thing objected to, exists of the same kind, and often more in degree, in a smoky room anywhere. 3. *Moisture from the condensed steam and the springs in the earth.*—Although there is much less of it, than in the air of a misty or rainy day. 4. *Rapid passage through the air.*—Although the effect is the same, as of the wind passing persons in a windy day; and much less than when in the open air the railway carriage moves against the wind. 5. *Sudden darkness.*—Although the change is less sudden, than when a person puts his hand before his eyes, or goes into a dark cellar, or when the lights in a room are suddenly extinguished. 6. *Noise.*—Although this is not so great as in many manufactures, or of military review firing. And be it remarked, that a man who chooses to pull up the glasses of the carriage, and carry the same air with him through the tunnel, absolutely avoids four of the alleged dangers, viz. the change in temperature, in purity of air, as to smoke and moisture, and the current; and by shutting his eyes and putting cotton in his ears, he may if he choose avoid the other two. The whole six objections fall properly under the head of *alarm from novelty* to a person ignorant and inexperienced. The effect, on any ordinary person, is in reality the same as of passing along any narrow street at night."* The *ventilation of tunnels* takes place, first, by the air blowing through them; secondly, by the effect of the perpendicular openings in them, called shafts, through which the air in winter, because then hotter than the atmosphere, ascends—in summer, because colder, descends—producing, in both cases, a change of the mass below; and, thirdly, by the passage through the tunnel of the trains of carriages driving the air along. "In any case," adds Dr. Arnott, "where these influences are insufficient, it would be easy, by hoisting a sail on one of the carriages of a train, which sail would nearly stretch across or fill the tunnel, absolutely to sweep out the whole of the air at each transit."

129. *Of Curvatures.*—It is scarcely possible to construct a line of railway perfectly straight; there must of necessity be *curvatures* of a certain amount. The effect of curvatures is to produce lateral friction of the flanches of the wheels against the sides of the rails. On this subject, Mr. Wood observes:—"All the wheels now used on railways, especially where curves occur on the lines, are constructed, so that the outside rim is conical, or is enlarged in diameter next the flanch; when, therefore, the carriages are passing round a curve, the wheels, being connected together by the axle, form as it were, a conical roller, running upon the rails with different radii; the larger radii being on the outside curve of the rail. This increase in the diameter of the wheel, running on the outside, compensates, to a certain extent, for the increased length of the outer curve of the rail; and if the radius of the curve be not less than the line which the two wheels of unequal radii would describe, the wheels will travel along the line without rubbing against the flanches. But, if the curve be more acute than such a line, then the flanches of the wheels are the only guides to keep the carriages on the rails." The same writer observes, that if the outside rail of the railway be elevated to such a height, above the inner rail, as to give to the axles of the

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* Arnott *On Warming and Ventilating.*

carriages resting upon the two rails, such an inclination as will produce upon the carriages a *gravitating force towards the centre of the curve*, equal in amount to that of the *centrifugal force outwards*, there will be no tendency in the carriages to upset, or to press the wheels against the rails. It is obvious that the smallest curvature should have a considerable radius: Mr. Wood states that a radius of 565 feet is less than ought to occur in any curvature on a railway. In going round a height, the radius ought to be considerably larger, in order to allow the engine driver to look out, so as to prevent collisions from trains travelling in either direction.

130. *Of Gradients.*—Gradients are inclinations of the road, and are obviously of two kinds, ascending and descending. 1. In the case of *ascending gradients*, in which the inclination exceeds a certain limit, additional power must be given to the engine, in order to overcome the increased effect of gravity. Various methods have been adopted for this purpose: a subsidiary locomotive engine is kept in readiness at the foot of the gradient, in order to assist the train on its arrival, as is generally adopted on the Liverpool and Manchester line; or a fixed engine is placed on the summit of the gradient, and communicates by a rope with the train at the foot of the plane; or the load is divided at the foot of the gradient, and the engine carries it up by two or more ascents, as has been occasionally done on the Rainhill inclination of the Liverpool and Manchester Railway. 2. In the case of *descending gradients*, the increased velocity arising from gravity must be checked by means of a break; this consists of a curved piece of wood, which fits the circumference of some of the wheels of the carriages, and is pressed upon them by a lever worked by the engine driver with more or less force, according to the declivity of the gradient, or the velocity with which it is desirable for the train to descend. The subject of gradients will be noticed again presently.

OF RESISTANCE ON RAILROADS.

131. *Different kinds of Friction.*—In all locomotive engines, a certain degree of obstruction, or *resistance*, is caused by *friction.* There are two kinds of friction, the *rubbing* friction of the axles sliding within their chairs or bearings,* and the *rolling* friction of the circumference of the wheels upon the rails; but, as both these retarding forces are in operation at the same time, it is usual to comprehend both kinds under the general term friction or resistance. Until a recent period, almost the total amount of resistance to the progressive motion of an engine was referred to the mechanical obstructions above mentioned. The *total amount of resistance* has been variously stated by different authorities: on a well-constructed level, it has been generally estimated at the 240th part of the gross load; on inclined planes, the ordinary resistance is, of course, increased by the effect of gravity, and the power of traction must be proportionably increased. According to this mode of calculation, an ascent of one foot on a plane of 240 feet, would require the power of traction to be doubled; on an ascent of two feet in 240, the power must be trebled; on an ascent of three feet, it must be fourfold; and so on. Hence, it appears that a very slight inclination involves a very considerable increase of the power of traction: the

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* The annexed figure represents the simplest form of axle, and plan of bearing. A represents an end view of an axle, which revolves in the direction of the arrow. B represents a cast or wrought-iron *chair*, which is secured to the framing of the carriage by bolts, with a semicircular *bearing* for the axle to work in. The bearings are placed within, or outside, the wheels of the carriage. The lubricating matter C is placed against the axle, so as to keep up a continual supply, and ensure a uniform action.

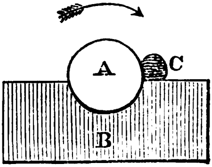

Fig. 74.

Rainhill inclination, on the Manchester railway, rises one foot in 96, and would, accordingly, require the amount of ordinary traction to be increased fourfold. But this mode of calculation has recently been called in question.

132. *M. Pambour's Calculations.*—In 1834, M. Pambour instituted a series of valuable experiments upon the Liverpool and Manchester Railway, in order to determine the amount of friction, or resistance to traction, in locomotive engines as at present constructed. The portion of the line selected was on the Sutton Plane, which is a uniform inclination of nearly 1 in 100; at the bottom of the plane, the line is nearly level. His plan was to start the carriages from a given point on the plane, to allow them to run down the plane, and to be brought to rest by their friction on the level part of the line below. Stakes were set up at intervals of 330 feet; the distances, and corresponding descent of level from the starting point to the different stakes, in feet, were carefully noted. The details of these experiments are described in the *Traité des Machines Locomotives* of M. Pambour. The conclusions at which he arrived, are as follow. 1. The average resistance of the carriages, without the engine and tender, is about 8 lbs. per ton of the gross weight of the carriages and load. 2. The average resistance of locomotive engines, in good order, is about 15 lbs. per ton of their weight. 3. The resistance of the engine is increased by the load at an average of about 1 lb. per ton. In these experiments, the average resistance of the single carriages was estimated at the 206th, that of the carriages in trains at the 262d, part of the weight. These results are considered by Mr. Wood as too favourable; they may, however, be taken as approximate estimations for locomotive engines as at present constructed.

133. *Dr. Lardner's Experiments.*—In the autumn of 1838, a series of experiments was performed by Dr. Lardner, in order to determine the mean amount of the resisting force opposed to the moving power; the plan adopted, was to observe the motion of trains descending steep inclinations.

Contrary to the opinion previously entertained, it was found that the acceleration was not uniform, but that it actually lessened with increase of speed. Thus, "if a certain speed were gained by a train in one second when moving at five miles an hour, a much less speed was gained in one second when moving ten miles an hour, and a comparatively small speed was gained in the same time when moving at fifteen miles an hour. In fact, the augmentation of the rate of acceleration appeared to diminish in a very rapid proportion as the speed increased: this suggested to me the probability that a sufficiently great increase of speed would destroy all acceleration, and that the train would at length move at a uniform velocity." It was found that the uniform speed thus attained, depended on the weight, form, and magnitude, of the train, and the inclination of the plane; that the same train on different inclined planes attained different uniform speeds, on the steeper planes a greater speed being attained. "From such experiments it followed, contrary to all that had been previously supposed, that the *amount of resistance* to railway trains had a dependence on the *speed;* that this dependence was of great practical importance, the resistance being subject to very considerable variation at different speeds, and that this source of resistance arises from the *atmosphere* which the train encounters. This was rendered obvious by the different amount of resistance to the motion of a train of coaches and to that of a train of low waggons of equal weight."

184. *Compensating effect of Gradients.*—"The tendency of the results of these experiments shows that low gradients on railways are not attended with the advantageous effects which have been hitherto ascribed to them; that, on the contrary, the resistance produced by steeper gradients can be *compensated by slackening the speed*, so that the power shall be relieved from as much atmospheric resistance by the diminution of velocity, as is equal to the increased resistance produced by the gravity of the plane which is ascended. And, on the other hand, in descending the plane,

the speed may be increased until the resistance produced by the atmosphere is increased to the same amount as that by which the train is relieved of resistance by the declivity down which it moves. Thus, on gradients, the inclination of which is confined within practical limits, the resistance to the moving power may be preserved uniform, or nearly so, by varying the velocity. The principle of *compensation by varied speed* being admitted, it will follow, that the time of transit between terminus and terminus of a line of railway laid down with gradients, varying from twenty to thirty feet a mile, will be practically the same as it would be on a line of the same length constructed upon a dead level; and not only will the time of transport be equal, but the quantity of moving power expended will not be materially different. The difference between the circumstances of the transport in the two cases will be merely, that, on the undulating line, a varying velocity will be imparted to the train, and a varying resistance opposed to the moving power; while, on the level line, the train would be moved at a uniform speed, and the engine worked against a uniform resistance."—Lardner *On the Steam Engine*, 7th edit., p. 408, &c.

LOCOMOTIVE ENGINES ON COMMON ROADS.

135. *Gurney's Steam Carriage.*—The *resistance* of carriages on *turnpike roads* has been made the subject of experiment by the Holyhead Road Commissioners, and has been estimated at not less than 72lbs. per ton of the gross weight. But the resistance on turnpike roads is not increased by *curvatures* in the same *proportion* as it is on railroads; and, hence, the increased power required by them is not so great *proportionally* on the former, as on the latter, kind of road. Further, it has been found that there is sufficient *adhesion* between the wheels of carriages and the surface of common roads, to propel a train of loaded carriages along them. These and other circumstances have

suggested the practicability of applying steam to the purpose of transport on common roads. Accordingly, in 1831, a steam carriage, constructed by Mr. Goldsworthy Gurney, plied regularly for four months between Gloucester and Cheltenham. The carriage performed this journey of nine miles four times a day. It carried, during the period of four months, upwards of 3000 passengers, without a single accident, at a greater speed than that of common stage coaches, and at half their fare. The value of coke consumed during this period was about £50. Mr. Gurney calculated, that a carriage weighing 35 cwt., working for eight hours, is enabled to perform the work of about 30 horses; that his propelling carriage, capable of carrying 18 passengers, would be equal to the weight of four horses; that the conveyance carriage would be of the same weight as a common stage coach capable of carrying the same number of persons; and that, accordingly, the weight of both together would be equal to the weight of a common stage coach, with four horses included. In order to enable the carriage to ascend hills, steam of a very high pressure must be employed; this may vary from 70 to 100 lbs. on the square inch. In 1829, Mr. Gurney travelled, in his steam carriage, from London to Bath, and back, surmounting all the hills on this road. His experimental carriage was found to be capable, in 1826, of ascending all the hills around London, not excepting the hill between Kentish Town and Highgate.

136. *Report of Gurney's Steam Carriage.*—But Mr. Gurney had to undergo the usual fate of inventors—the most unscrupulous opposition arising from ignorance and prejudice. The obstructions thrown in his way were so numerous, that, after a successful experiment of four months, his plan was abandoned. Mr. Gurney petitioned Parliament, and a committee was appointed to inquire and report upon the subject. The following extracts from the Report contain some interesting matter on this subject: "1. Without increase of cost, we shall obtain a power which will ensure a rapidity of internal communication far beyond the

utmost speed of horses in draught. 2. Nor are the advantages of steam power confined to the greater velocity attained, or to its greater cheapness than horse draught. In the latter, danger is increased, in as large a proportion as expense, by greater speed. In steam power, on the contrary, there is no danger of being run away with, and that of being overturned is greatly diminished. It is difficult to control four such horses as can draw a heavy carriage ten miles per hour, in case they are frightened, or choose to run away; and for quick travelling they must be kept in that state of courage, that they are always inclined for running away, particularly down hills and at sharp turns of the road. In steam, however, there is little corresponding danger, being perfectly controllable, and capable of exerting its power in reverse in going down hills. 3. Steam has been applied as a power in draught in two ways; in the one, both passengers and engine are placed on the same carriage; in the other, the engine carriage is merely used to draw the carriage in which the load is conveyed. In either case, the probability of danger from explosion has been rendered infinitely small, from the judicious construction of boiler which has been adopted. 4. The danger arising to passengers from the breaking of the machinery need scarcely be taken into consideration. It is a mere question of delay, and can scarcely exceed in frequency the casualties which may occur with horses." The Committee conclude their Report by the following summary of propositions, of the truth of which they state that they have received ample evidence:—

1. "That carriages can be propelled by steam on common roads at an average rate of ten miles per hour.
2. "That at this rate they have conveyed upwards of fourteen passengers.
3. "That their weight, including engine, fuel, water, and attendants, may be under three tons.
4. "That they can ascend and descend hills of considerable inclination with facility and safety.

5. "That they are perfectly safe for passengers.
6. "That they are not (or need not be), if properly constructed, nuisances to the public.
7. "That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.
8. "That, as they admit of greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages will cause less wear of roads than coaches drawn by horses."

137. *Hancock's Steam Carriage.*—Mr. Hancock's steam carriage differs from the preceding, in carrying the engine and the passengers on the same carriage. It weighs about 3½ tons, and accommodates 14 passengers. Various other contrivances have been projected for the application of steam engines on turnpike roads, but none of these have been brought into practical operation. Among other aspirants to success in this scheme, may be named Mr. Ogle of Southampton, and Dr. Church of Birmingham.

RECAPITULATION.

103. Into what two classes are steam engines divided? Why is the term *low-pressure engine* in many cases incorrect? What is the difference between the single acting Cornish engine and the single acting engine of Watt? Why is a *non-condensing* engine necessarily a *high-pressure* engine? How is it that in high-pressure engines, the whole force of the steam is not turned to account? What parts of a non-condensing engine are dispensed with in a condensing engine?—104. Explain the principle of Leupold's engine.—105. Describe the construction of Trevithick and Vivian's engine. What was its perform-

mance?—106. What is meant by skidding of the wheels? What contrivances for obviating this imaginary difficulty were successively introduced?—107. How does the adhesion between the wheels of a locomotive engine and the rail vary with the state of the weather? What is the amount of adhesion, as determined by experiment?—108. Explain the method by which locomotion was effected by Stephenson's Killingworth engine?—109. What improvement was subsequently made in this engine? Explain the principle of the *steam springs* adopted in this engine. What is the objection to this contrivance?—110. What advantages do locomotive possess over stationary engines?—111. State the conditions under which the engines were constructed for the "Liverpool Experiments."—112. What was the performance of the "Rocket" engine? Explain, generally, the construction of this engine.—113. What was the performance of the "Sans Pareil" engine? For what reason was it disqualified for competition?—114. What was the performance of the "Novelty" engine? Why was it withdrawn? Explain, generally, its construction and mode of action.—115. What were the comparative weights of the new and the old engines? What were their relative powers? What was the difference between their evaporating powers? To what cause was this to be attributed?—116. What improvement was introduced, at this period, in the position of the cylinder? By what means was the evaporating surface increased? What change was made in the position of the cranks?—117. What are the principal features in Mr. Bury's engines? What is the danger arising from cranked axles? How may this danger be obviated?—118. What was the performance of the engines "Victory" and "Samson," in 1832?—119. What is the average amount of water evaporated by the best modern locomotive engines?—120. Describe the several parts of the modern locomotive engine, with reference to the figures at page 165. Explain the general working of a locomotive engine.—121. What is the nature of the smoke-consuming apparatus of Mr. Hall?—

123. What is Mr. Hall's contrivance for economizing the waste steam? What is the object of his distributing plate?—124. What alterations are introduced in Stephenson's new patent engine? What advantages are anticipated from these alterations?—125. Of what materials are rails constructed? What are the forms of rail now in use?—126. What is the usual width required between the rails of a track; between the two tracks of a line; outside the rails; for the slopes; and for the drainage?—127. What are turnouts? At what angle are they commonly placed?—128. How are tunnels ventilated? How may the popular prejudices against tunnels be answered?—129. How is the friction caused by curvatures on the road prevented?—130. What are gradients? What are the methods adopted for ascending inclined planes? How is the velocity checked on descending planes?—131. What was the amount of *resistance* formerly attributed to *friction*, on railroads? In what ratio would this resistance be increased on inclined planes?—132. What is the amount of resistance, as estimated by M. Pambour?—133. What effect has increase of speed on the acceleration of a train? What new source of resistance was discovered by the experiments of Dr. Lardner?—134. Explain the compensating effects of ascending, and of descending, gradients.—135. What was the performance of Mr. Gurney's steam carriage on turnpike roads?—136. What was the general purport of the Report made on this method of locomotion?

CHAPTER X.

OF STEAM NAVIGATION.

138. *Preliminary Remarks.*—The application of steam to the purpose of propelling vessels, the proportionate impulse which has hereby been communicated to commercial prosperity, and the direct relation of the invention to the art of warfare, are among the most remarkable phenomena of the present day. The beneficial effects derived from this mode of employment of steam power may be estimated by the rapid extension of its use, in our own country alone, within a comparatively short period of time. In 1812, a solitary steam boat began to ply on the Clyde; in 1825, fifty-one steam boats were in operation on the same river; in 1837, sixty-three vessels, comprising a burden of 6,644 tons, were sailing on the Clyde. In Great Britain and Ireland, in 1814, there were, exclusive of government vessels, eleven steam vessels, of 542 tons burden in all; in 1828, this number was increased to 344, with a burden of 30,912 tons; in 1838, there were 760 vessels, of 78,664 tonnage, and 56,490 horse power; of these, about 480 were river steamers and small coasting vessels, and 280 large coasting and marine vessels. The total extent to which steam power was applied in Great Britain, in 1825, was estimated by Baron Dupin as equivalent to the power of 320,000 horses in constant action; from that period its employment has been prodigiously increased; the amount of capital afloat in steam ships may be said to be nearly *six millions of money*. In America, steam communication has proceeded with an equally rapid progress. In 1807, the first American steam boat was launched at New York; in 1838, the whole number of steam vessels

employed in that country, was from 700 to 800. In a late return from the secretary of the Treasury of the United States, it is stated, that on the western and south-western waters alone, near 400 vessels are supposed to be running, where none were used till 1811; and where, in 1834, the number was computed to be 234. On the Ohio river alone, in 1837, 413 different steam boats are reported to have passed through the Louisville and Portland Canal. As an illustration of the rapid increase of business in steam boats on the Ohio, the number of their passages throughout the Louisville canal was, in 1831, 406 passages, and 1501 passages in 1837, being nearly fourfold in six years. In this path of national improvement, in the discovery of physical principles and their application to mechanical operation, it is the proud boast of Great Britain, that she has taken the lead. In the words of Tredgold, "No new principle, no new combination of principles, has yet been derived from a foreign source; the most perfect of foreign steam engines being professedly copied from British ones, and not unfrequently manufactured by British workmen." We are now placed in that interesting period of time, when steam navigation promises to connect the most distant habitable parts of our globe, its extension being limited only by local deficiencies of the *material* to which it owes its power. Already has the surface of the ocean, as well as that of the land, been traversed by a network of lines ramifying from the great centres of civilization. Communication is now opened between the Old and the New Continents by an easy passage of only fourteen days; and a project is now in contemplation for establishing a line of steam communication between Great Britain and India. The moral and political results arising from the extended operation of this power can at present be but feebly calculated; but the philanthropist may well indulge a hope, that the dissemination of the arts, sciences, literature, and natural productions, of the most favoured spots of the earth, may, at no very distant period, effect the most glorious *revolution* in the annals of man.

The subject of this chapter may be arranged under the following heads:—

1. *History of Steam Navigation.*
2. *Inland and Marine Engines.*
3. *Of Marine Boilers.*
    1. *Form of boiler.*
    2. *Indicators of saltness.*
    3. *Blowing out; brine pumps.*
4. *Of the Cylinder of the Marine Engine.*
    1. *Relation between the*
        1. *Dimensions of the Cylinder, and*
        2. *Power of the Engine.*
    2. *Application of the Steam.*
5. *Of the Condenser and Air-Pump.*
    1. *Common Injection Condenser.*
    2. *Mr. Hall's Patent Condenser.*
        1. *Distilling Apparatus.*
        2. *Steam Saver.*
        3. *The "Queen" Steam ship.*
        4. *The "Megæra" and "Volcano."*
        5. *The "British Queen."*
    3. *Howard's method of vaporization.*
6. *Of Paddle Wheels.*
    1. *Paddle wheels with fixed floats.*
        1. *Common paddle wheel.*
        2. *Field's cycloidal wheel.*
    2. *Paddle wheels with feathering floats.*
        1. *Buchanan's paddle wheel.*
        2. *Morgan's paddle wheel.*
    3. *Hall's reefing paddle wheel.*
7. *Engines of the Steam Packet "Ruby."*
    Description of a Marine Engine.
8. *Engines of the Steam Frigate "Gorgon."*
9. *Of the Archimedean Screw Propeller.*
10. *Proportion of Power to Tonnage.*
11. *Steam Navigation in America.*

139. *Early History of Steam Navigation.*—The project of Blasco de Garay, in 1543, has been already noticed (p. 20). The application of steam to navigation by Hulls has also been briefly described and illustrated (p. 32); his method of converting the reciprocating into the rotatory motion was ingenious, but not so simple as that of the crank. From the date of his invention, it appears that his engine was a modification of the atmospheric engine of Newcomen. In 1785, two Americans, James Ramsay, of Virginia, and John Fitch, of Philadelphia, claimed the renown of discovering the application of steam to navigation, but their plan was not reduced to practice. The merit of the invention appears to belong to three British subjects, and the first successful application of it to an American; their respective claims must be adjusted by reference to dates. In 1788, a steam boat was constructed by Mr. William Symington, of Falkirk, under the patronage, or, as some say, the directions, of Mr. Patrick Miller, of Dalswinton, and Mr. James Taylor, the tutor of his family; this boat was capable of being driven at the rate of five miles an hour. In the following year, Mr. Symington constructed a larger boat, which was tried on the Forth and Clyde Canal, and went at the rate of seven miles an hour. In 1801, Mr. Symington was encouraged by Lord Dundas to construct an experimental steam boat for towing vessels on the Forth and Clyde Canal; it had a steam cylinder of twenty-two inches in diameter, and four feet stroke; it appeared well adapted to the purpose for which it was made; the plan was, however, abandoned, probably on account of the motion of the water injuring the banks of the canal. Mr. Fulton, an American engineer, and Mr. Henry Bell, of Glasgow, had an opportunity of inspecting the steam boat, constructed in 1801, by Mr. Symington; and the consequence was that, in 1807, Mr. Fulton launched the first steam vessel, the "Clermont," on the Hudson, and in 1812, Mr. Bell fitted up another, the "Comet," for the Clyde; these were the two first vessels of the kind ever employed for public

service in either hemisphere. Mr. Fulton's engine was made in 1804 by Messrs. Boulton and Watt; its first voyage was performed between New York and Albany, a distance of 160 miles, in about thirty hours. Mr. Bell's boat plied the whole summer from Glasgow to Helensburgh; the engine exerted a force of about three horse power; the weight of the vessel was about twenty-five tons. The rate of speed of both the above vessels was about five miles an hour. Shortly after the experiment of Fulton's boat, Mr. Stevens, of Hoboken, in America, performed a successful voyage, by means of steam, on the open sea; his construction of the vessel, and modification of the machinery, appear to have realized the great objects of steam navigation. In our own country, the enterprise of steam navigation on the open sea began to be successfully prosecuted, in 1818, by Mr. David Napier; by his industry, communications were opened between Great Britain and France, during the stormy period of winter; post-office packets were regularly established between Dover and Calais, between Liverpool, Greenock, and Belfast, between Holyhead and Dublin; and before the year 1822, a fleet of commercial steam ships was constructed, combining greater power and speed than any at that time in Europe; these vessels ranged from 150 to 240 tons burden, and their engines from 60 to 70 horse power. In 1822, the "James Watt" steam vessel plied between Leith and London; this vessel was of 448 tons burden, and carried two engines of 50 horse power each; its rate of speed was ten miles an hour. The "United Kingdom," the engines of which were furnished by Mr. Napier, and were of 200 horse power, was the noblest vessel constructed at that period. Various improvements were subsequently introduced by inventors whose names will appear in the following pages. In completing this brief sketch of the history of marine navigation, it will be sufficient to notice the performance of a steam vessel which plied for twelve months, in the years 1836-37, between Greenock and Liverpool, a distance of 220 miles: the "Unicorn" performed this voyage, during summer and winter, with variable loads of passengers and merchandise, one hundred and forty-six times, at a speed of eleven miles an hour, with almost perfect regularity. This vessel was afterwards transferred to the station between Great Britain and America.

140. *Differences between Inland and Marine Engines.*—1. The inland locomotive engine is propelled by means of wheels attached to an axle, the axle being worked by two cranks; the steam ship is propelled by means of a pair of *paddle wheels* attached to the two extremities of an axis, or *shaft*, placed across the vessel, and projecting at each end beyond its timbers; the shaft is worked by two cranks. So far, the mode of propulsion in both cases is similar; in both, the cranks are placed at right angles to each other; but in the former case, the cranks are worked by a single engine with two cylinders; in the latter, by *two engines*, each having a single cylinder, and acting upon a common shaft. Locomotion is effected, in the former case, by the adhesion of the wheels to the rails; in the latter case, by the reaction produced by the paddles striking the water in the opposite direction to that in which the vessel is proceeding. 2. The engines used on railways, are of the high-pressure kind; in marine navigation, low-pressure condensing engines are always employed in this country, and they are constructed in all respects on the general plan of Watt's double acting engine, with slight modifications in the forms and relative position of the parts. On the rivers of America, where lightness of weight is of importance, high-pressure engines are frequently employed. 3. In Watt's engine, there is only one beam, and this is placed above the cylinder and piston-rod; in the marine engine, there are *two beams*, and they are placed *below* the cylinder and piston-rod. The connecting-rods, in the latter engine, are therefore presented *upwards* towards the cranks which they put in motion, instead of being presented downwards, as in the former engine. In the marine engine, the machinery is, in fact, *inverted* with reference to the beam, the

object being to keep the bulk and weight of the engine as low as possible in the hull of the vessel (see par. 145). In the steam boats used on the American rivers, the original position of the parts is retained, and the machinery extends to a considerable height above the deck. 4. The *proportion of the cylinders* differs in the two kinds of engine. In the land engine, the length of the cylinder is usually double its diameter; in the marine engine, the diameter is very little less than the length. As necessary consequences of this, the stroke of the latter engine is much shorter than that of the former, in proportion to its power; the crank is shorter; and the sphere of vertical action of the moving parts is limited in a corresponding degree. 5. In both kinds of engine, there are several parts which do not essentially differ; in both there are condensers, air-pumps, and a mechanism for working the valves. In the marine engine, equalization of power is not of the same importance as in stationary land engines; the governor and its apparatus are, therefore, not required.

OF MARINE BOILERS.

141. *Form of Boiler.*—In the construction of the marine boiler, it is necessary to combine the greatest possible efficiency with the least weight. A very compact form of boiler is, therefore, adopted, in which a large surface is exposed to the heat of the furnace, and a proportionate increase of evaporation produced. The annexed figure represents a horizontal section of a boiler employed in some of the government vessels. It consists, in reality, of three boilers, any two of which may be used, in case of any accident happening to the third.

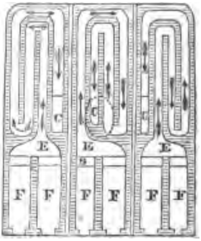

Fig. 75.

There are three pairs of furnaces F F, communicating with three flues E, which traverse the boiler in four directions, two forward and two backward, in the direction of the arrows placed in the white spaces. The intermediate dark parts represent the water contained within thin plates; by which means the heated air acts upon every portion of the water at a great advantage; it appears that the evaporation thus produced, when compared with that effected by the boiler of a land engine, is as three to two, with the same consumption of coal. The heated air having traversed these meandering flues, and having reached the points C, enters into three curved flues, represented by the letters B, in the transverse section of the same boiler, fig. 76; the curved flues terminate in the chimney. Three dampers are placed in the curved flues at the point where they merge into the chimney, by which means the communication of any one of the three boilers with the chimney may be cut off at pleasure. In the plan of boiler here described, the flues are all upon the same level; in other cases, the flues are made to traverse two levels, the one placed above the other, by which means a greater heating surface is obtained.

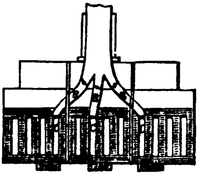

Fig. 76.

142. *Indicators of Saltness of the Water in Boilers.*—The amount of earthy and saline deposits which takes place in the boilers of land engines is not great, and may be easily removed. But in steam vessels, the case is very different: from the constant supply of sea water, incrustations of salt and sulphate of lime are deposited in the boiler, and, these substances being bad conductors of heat, the boiler may become red hot, leaks may be produced, or even explosion may take place. 1. The *degree of saltness of the water in the boiler* of an engine may be ascertained by means of the *thermometer.* Some experiments were made on this subject

by Messrs. Maudsley and Field, with the view of maintaining the water in a boiler at the same temperature, and at the same degree of concentration. They found that sea water boiling under the usual low-pressure standard of 2½ pounds on the square inch, will arrive at 226° Fahr. in 24 hours; at 230° in 48 hours; and at 232° in 60 hours, &c.; in the last condition it contains 11-32nds of its bulk of salt. At 232° the solution is saturated, and salt is deposited, the concentration having constantly increased with the temperature. The density of the water increases with its concentration, and more heat is required for its evaporation. Since the temperature, therefore, increases with the concentration, under the same pressure, the thermometer becomes an indicator of the saltness of the water, and, accordingly, of the danger to which the boiler is exposed from the effects of incrustation. Mr. Dinnen states, that having carefully noted the degree of saturation of the water in the boilers (which were made of copper) at various periods of the day, during a voyage from Falmouth to the Mediterranean and back, the boilers were on each successive examination found perfectly clean and free from marine deposit, with the exception of a slight film, the thermometer being at 215°, and not having varied in excess throughout the voyage. Hence the delay of "blowing out" completely on the voyage was unnecessary. 2. Dr. Lardner has suggested the use of a self-registering instrument, which should not only indicate, but record, from hour to hour, the degree of saltness of the water in the boiler; this contrivance is founded on the *difference of pressures* under which the salt water of the boiler, and fresh water of the same temperature, are found to boil. "A small vessel of distilled water being immersed in the water of the boiler, would always have the temperature of that water, and the steam produced from it communicating with a steam gauge, the pressure of such steam would be indicated by that gauge, while the pressure of the steam in the boiler, under which pressure the salted water boils, might be indicated by another gauge. The difference of the pressures indicated by the two gauges, would thus become a test by which the saltness of the water in the boiler would be measured. The two pressures might be made to act on opposite ends of the same column of mercury contained in a siphon tube, and the difference of the levels of the two surfaces of the mercury would thus become a measure of the saltness of the water in the boiler."* 3. Another contrivance for indicating the saltness of the water in the boiler, and the proper periods for blowing out the supersalted water, has been recently adopted by the Messrs. Seaward. It consists of the steam gauge (fig. 37, page 95), by which the level of the water in the boiler is indicated. In the water of the gauge are placed two hydrometer balls of different weight, but both sufficiently heavy to sink in a solution of salt, in which the salt constitutes 1-32nd of its entire weight, which is the ordinary condition of sea water. When the solution becomes so far concentrated that the salt constitutes 5-32nds of the whole weight, the lighter ball rises to the surface, and affords an indication of the necessity of blowing out. When the quantity of salt amounts to 6-32nds, the heavier ball rises, and indicates that the concentration has proceeded to an injurious degree. When the quantity of salt amounts to 9-32nds, a deposition begins to take place.

143. *Process of blowing out; Brine Pumps.*—In sea-going vessels, it is customary at certain intervals to *blow out* the boilers. This process consists in discharging from the boiler into the sea the whole, or a portion, of the concentrated salt water, and supplying its place with sea water; this is effected by means of *blow-off cocks*, placed at the lower part of the boiler, where the more concentrated and denser portions of the solution collect: on opening these cocks, the weight of the water, and the pressure of the steam acting upon its surface, drive out the water from below. This process obviously involves a loss of time and a waste of fuel; the latter was estimated by Tredgold at

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* Lardner *On the Steam Engine*, page 453.

1-54th part. In government vessels, the engineers are instructed to blow out the boilers completely every three or four days; in other cases, it is usual to blow out a certain quantity of the contents of the boiler every two hours, and supply its place with sea water, which is introduced into the condenser, where it is mixed with the condensed steam, and carried to the boiler. By this change of water, a solution containing perhaps thirty-six per cent. of salt is discharged, and its place supplied by a solution containing only three per cent., this being the proportion in which salt exists in sea water (page 6). Messrs. Maudsley and Field have introduced a method by which the saltness of the water in the boiler is maintained at a constant degree. This consists in the application to the boiler of pumps, called *brine pumps*, for the purpose of discharging into the sea the supersalted water, or brine. These pumps, as well as the pumps which supply the boiler with sea water, are worked by the engine, and are consequently in perpetual action. The ingenuity of the contrivance consists in the adjustment effected by the two kinds of pump, between the supply and the discharge of salt, the brine pumps discharging as much salt dissolved in a small quantity of water, as the feed pumps are capable of supplying in a large quantity of water; the quantity of salt thus continues constant, while the difference between the quantities of water, supplied and discharged, is converted into steam, and devoted to the working of the engine. If, for instance, the discharged brine contain 5-32nds of salt, and the supplied sea water contain only 1-32nd, it will be the duty of the feed pump to supply five times as much water as the brine pump discharges; and of these five parts, four are available for the purpose of evaporation. By means of another happy contrivance of Messrs. Maudsley and Field, the brine, previously to its being discharged into the sea, is made to communicate a great portion of its heat to the supply of sea water. For this purpose, the brine is conveyed away from the boiler to the sea in a tube, contained within another tube, in which latter the supply is conveyed from the sea to the boiler. Thus the hot and the cold liquids pass in contrary directions, the former *within* the latter; by this means the temperature of the brine is reduced to about 100° previously to its being discharged into the sea.

OF THE CYLINDER OF THE MARINE ENGINE.

144. *Relation between the dimensions of the Cylinder, and the power of the Engine.*—It has been stated that the diameter of the cylinder, in marine engines, is usually little less than its length. The *power of an engine* is commonly estimated by the *dimensions of the cylinder;* the number of inches of the diameter of the cylinder is taken as the estimate of the horse power of the engine, a cylinder of 74 inches diameter being generally considered to yield a power equal to that of 200 horses. This rule, however, must be applied with caution, for the power of an engine, as inferred from the dimensions of its cylinder, may be merely *nominal*, and fall far below the estimate, owing to the imperfect construction and adjustment of the other parts of the engine; whereas, on the other hand, the real power of an ably constructed engine may be far above the estimate, derived from the dimensions of its cylinder. The following table was constructed by Mr. Scott Russell from a comparison of the practice of the most eminent marine steam engine makers, with the principles of their construction. He states that, under the dimensions given, the engines of best construction will give out from one-fourth to one-third more than their nominal power; that the proper nominal power of a cylinder of 74 inches is above that of 225 horses, and that its actual effective power, as given out in the ship, is more than that of 300 horses. The variations between the *nominal* and the *useful* effect of engines are owing, not only to good or bad construction, but to certain practices which are exclusively of a mercantile character.

Table of the Dimensions of the Cylinder of a Marine Steam Engine of given Horse power.

Nominal Power.	Dimensions of Cylinder.	
	Diameter (within).	Length of Stroke.
10 Horse power	20 Inches	2 Feet 0 Inches
15 ,,	24 ,,	2 2 ,,
20 ,,	27 ,,	2 6 ,,
25 ,,	30 ,,	2 10 ,,
30 ,,	32 ,,	3 2 ,,
35 ,,	34 ,,	3 3 ,,
40 ,,	36 ,,	3 6 ,,
45 ,,	38 ,,	3 9 ,,
50 ,,	40 ,,	4 0 ,,
60 ,,	43 ,,	4 3 ,,
70 ,,	46 ,,	4 6 ,,
80 ,,	49 ,,	4 9 ,,
90 ,,	52 ,,	5 0 ,,
100 ,,	55 ,,	5 6 ,,
110 ,,	57 ,,	5 6 ,,
115 ,,	57 ,,	5 9 ,,
125 ,,	59 ,,	6 0 ,,
130 ,,	60 ,,	6 0 ,,
150 ,,	62 ,,	6 3 ,,
165 ,,	65 ,,	6 6 ,,
175 ,,	66 ,,	6 6 ,,
200 ,,	70 ,,	7 0 ,,
225 ,,	73 ,,	7 3 ,,
250 ,,	76 ,,	7 6 ,,
275 ,,	79 ,,	7 9 ,,
300 ,,	82 ,,	8 0 ,,
350 ,,	87 ,,	8 6 ,,
400 ,,	92 ,,	9 2 ,,
500 ,,	100 ,,	10 0 ,,

The table shows that the power of the steam engine increases more rapidly than the area of the cylinder or the square of the diameter. By the rule of the square of the diameter, the power of an engine of 74 inches would be about 200, instead of about 225; and 100 inches diameter would give only 333 horse power; but the same rule would give too small a diameter for the lower powers. The engines of the dimensions stated on the table will all work to more than their nominal power. In deviating from the proportions given in the table, a longer stroke will be preferable to a shorter; and, with the necessary alterations required for high velocities of the piston, a longer stroke working the steam expansively is likely to be attended with many advantages: the pressure and strain upon the working parts of the engine are lessened in proportion to a given power; all the parts of an engine may be lighter than with a shorter stroke and a greater diameter of cylinder. A short stroke has, however, this advantage—that with a given length of lever and connecting-rod, the angles of oblique pressure are smaller, and the intervals of time between maximum and minimum pressure are shorter. The velocity of the piston in the cylinder of a steam engine is generally reckoned in this country at 220 feet a minute, and all the arrangements of the engine and its work are made on that principle. Mr. Russell says, we can find no better reason for this than that a horse going at that speed, viz. two miles an hour, can draw 150 lbs. for eight hours a day, all the year round. He adds, that the rule is as universal in its acceptation as it is groundless and injurious; and that with large condensers, and large ports and valves, double the speed may be employed with great advantage.*

145. *Mode of applying the Steam in the Marine Engine.*—The mode by which the elastic force of the steam is communicated directly to the moving parts of the engine, may

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* J. Scott Russell *On Steam Navigation*, p. 270.

now be briefly described. It has been stated (p. 199), that the machinery in a steam engine, compared with that of a stationary land engine, is *inverted* with reference to the beam. In the land engine, the beam is placed above the cylinder, and is *pushed up* and *pulled down* by the piston-rod; in the marine engine, the beam is placed beneath the cylinder, and is *pushed down* and *pulled up* by the piston-rod. The method by which this is effected may be seen in the two following figures. 1. Fig. 77, represents a cylinder with its piston and rod; to the top of the rod *r* is attached a cross bar *f f*, the extremities of which project a little beyond the sides of the cylinder; to the extremities of this cross bar are attached vertical rods *f e*, *f e*, the lower ends of which are connected with the beams, as represented at *e* in fig. 78; the rods *f e* furnish the parallel motion, and serve to elevate and depress the extremities of the beams. In fig. 78, only one of the beams is seen, the other being on the opposite side of the cylinder, and connected with the opposite rod of the cylinder.—2. In the land engine, the connecting-rod is *pushed down* and *pulled up* by the beam; in the marine engine, the connecting-rod is *pushed up* and *pulled down* by the beam. This is obviously the case in fig. 78, in which the beam, working on a pivot *p*, produces the reciprocating motion of the connecting-rod *c b;* this rod is connected with the crank at *c*, and a revolving motion of the crank is effected round the axis *a* in the direction of the dotted circle. The reader may compare the action here

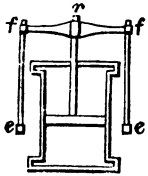

Fig. 77.

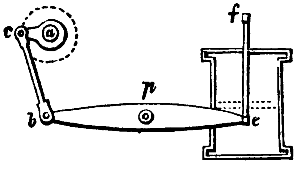

Fig. 78.

illustrated with that of the engine at page 60 of this treatise: the *inversion* will be immediately seen.—3. In fig. 79, the action of both the beams of each engine upon the cranks, and of these upon the axle, is illustrated. The letters *e e*, *e e* represent the lower extremities of the connecting-rods *c b* (fig. 78) at the points of their attachment to the beams. These extremities are connected together by the cross bars *e e*, *e e;* at the centres *o*, *o*, of these cross bars, the vertical bars *o c*, *o c*, are attached, and these act immediately upon the cranks, one of which is represented at its dead point, the other at right angles to the shaft *a a*. By this arrangement, it is evident that the paddle wheels *w w*, placed on the extremities of the shaft, perform one revolution for each reciprocating motion of the beams.

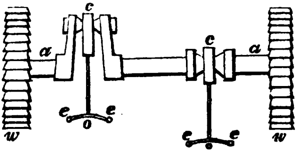

Fig. 79.

OF THE CONDENSER AND AIR-PUMP.

146. *Condensation by Injection.*—In the course of this treatise, various modes of condensation have been noticed. Thus, in the engine of Savery, steam is condensed in the vessel in which its elastic force is employed, by projecting cold water against the *exterior* of that vessel (p. 24); in Newcomen's engine, condensation takes place also in the steam vessel, by injecting cold water into the *interior* of the vessel (p. 27). In other cases, steam is condensed in a separate vessel, by exposing it to large surfaces of cold water, as in the engine of Cartwright (p. 71), or by injecting cold water among it, as in the engines of Watt (p. 40, 60). The method

of *condensation by injection* has for a long time been generally supposed to be the most rapid, and the vacuum produced by it the most complete; it has, consequently, been generally adopted in steam vessels. The *size of the condenser* in Watt's engines, considered in relation to the cylinder, may be seen in the engravings at the references above given; in the marine engine, the relative size of the condenser appears not to have been determined; a condenser of about one-half the size of the cylinder is of convenient dimensions, but it may exceed, or fall short of, this size in many cases without loss of efficiency. In Watt's engines, the *injection water* is thrown into the condenser from a cistern provided for that purpose; in the marine engine, sea water is introduced into the condenser through a pipe in the side of the vessel, which is regulated by a cock. The *condition of the vacuum* produced in the condenser is tested by means of a barometer gauge (p. 121); the great object with engineers is to produce as perfect a vacuum as possible. But Mr. Russell observes that a vacuum may be too good, and become a loss instead of a gain; he adds, that if the barometer stand at 29½ inches, the standard of this country, *the vacuum in the condenser is too good, if it raise in the barometer more than* 28 *inches of mercury;* and that the best elasticity or temperature in the condenser depends on the elastic force of the steam in the boiler. Thus: "With steam of 5 lbs. in the boiler, the elasticity of maximum effect in the condenser is at 93° Fahr., and the best vacuum in the barometer is 28. With steam of 7½ lbs. in the boiler, the elasticity of maximum effect in the condenser is 95° Fahr., and the best vacuum in the barometer is 27·8. With steam of 10 lbs. in the boiler, the elasticity of maximum effect in the condenser is 97°, and the best vacuum in the barometer is 27·5. In like manner, it would be found that with steam of 50 lbs. in the boiler, worked expansively, or in Cornwall, the best vacuum in the condenser would be about 26° on the barometer. To obtain a vacuum of 29½ with the weather glass at 29·75, and steam at 7½ lbs. would be to sacrifice four horse power out of every hundred. In a day when the barometer is as low as 28½ inches, the vacuum in the condenser should indicate 26·8. In speaking of the vacuum in the condenser, it would save much ambiguity to indicate the elasticity merely of the gas in the condenser. Thus, if the barometer stand without at 29½, and the barometer of the condenser at 28, it might be stated that the steam in the condenser stands at 1½, being the point of maximum effect; and the indication would at all times convey more precise information." (*S. Russell*, p. 277.) The *relative positions* of the cylinder, condenser, and air-pump, in the marine engine, are the same as in Watt's engines, already referred to. The dimensions of the *air-pump* vary from 1-8th to 1-5th of the volume of the cylinder. Mr. Russell states, that half the stroke of the cylinder, and one-third of the area of the cylinder, or one-third of the stroke of the cylinder, and one-half of the area of the cylinder, are common proportions for the air-pump.

147. *Mr. Samuel Hall's Patent.*—Within the last few years, Mr. Samuel Hall, of Basford, near Nottingham, has brought into practical operation a plan of condensing steam by the external application of cold water, without the process of injection. This method was attempted, about the year 1776, by Mr. Watt, but was abandoned by him from the supposed impracticability of producing an effective vacuum without injection, and for other reasons. As the advantages proposed by Mr. Hall's patent condenser are considerable; as the apparatus has already been applied to many land and marine engines; and as the success of the invention has a very important relation to the project of steam communication with India, the subject will be here treated with the consideration it deserves. The following is the specification of Mr. Hall's patent:—

"The objects of my invention (which invention I confine to steam engines worked by a vacuum produced by condensation) are to condense, without injection water (for the purpose of creating as good a vacuum as is obtained in well-known injection engines), the steam which passes through the engine for the working thereof, and also to condense for the most part (if not wholly) that portion of steam which usually escapes into the atmosphere through the safety valves, when the pressure of the steam in the boiler is too high during the working of the engine; in order that the water resulting from the condensation of such steam, may be returned into the boiler. And also, further, to supply so much more distilled water to the boilers of the above-mentioned description of engines, as is required to supply and replace any waste that may take place in the working thereof, in order to avoid the introduction of any water (into the boilers) containing saline or other extraneous matters.

"My invention does not consist in the novelty of any one of the five apparatus hereinafter mentioned, but in the combination of the whole five, or at least three out of the five, within proper proportions (as hereinafter described) as regards the first three, which I have found, by experience, to be beneficial, and from want of knowing and observing which, I have reason to believe that all persons who have made former attempts of the same nature have failed. I now proceed to describe the above-mentioned five apparatus, consisting of—

"First, a sufficient quantity of metallic surfaces, in the form of vessels, channels, passages, or pipes, of any convenient form, arrangement, or construction.

"Secondly, a pump, or any other proper apparatus for the passing of a sufficient quantity of cold water amongst such above-mentioned pipes, not only to condense all the steam of steam engines, but also to cool the water resulting from the condensation thereof to as low a temperature as (or even lower than) that of the mixture of the condensed steam and injection water, which is discharged from the air-pumps of injection engines, in order to produce, by such application of cold water, when used in combination with the metallic surfaces, as above stated, and with the air-pump hereinafter mentioned, as good a vacuum as is obtained, and well known in such injection engines, if not indeed a still more perfect vacuum. The quantity of cold water which I employ is ten gallons for such condensation of such 60,000 cubic inches per minute.

"Thirdly, the ordinary air-pump of the capacity hereafter stated to produce, when in connexion with the before-mentioned two apparatus, a sufficiently perfect vacuum, as above defined.

"Fourthly, an apparatus for distilling water to replace the waste of water that may take place in the working of the engine, in order to avoid, as above mentioned, the introduction of any water into the boilers containing saline or other extraneous matters.

"Fifthly, an apparatus (which I call the steam saver) for saving the steam that usually escapes into the atmosphere from the safety valves, when it becomes of too high pressure during the working of the engine, the apparatus causing such steam to pass into the condenser, to be converted into water, and returned into the boiler. It may be proper here to remark, that within certain limits, which experience will readily suggest, the above-mentioned proportions of metallic surfaces of cold water, and capacity of the air-pump, may be varied in a certain inverse order; that is to say, if the cold water be diminished, the extent of metallic surfaces, or the capacity of the air-pump, or both, should be increased. And, on the other hand, if the extent of metallic surfaces be diminished, the quantity of cold water, or the capacity of the air-pump, or both, should be increased to produce the same effect.

"Having now described the five several apparatus, the combination of which (within proper proportions, as hereinbefore described, as regards the first three) constitutes my invention, I proceed again to define and explain the extent of my claims; I now therefore state, that I do not claim the exclusive use of any one of the five apparatus herein described, taken separately, some of them, if not all, having been used before; nor indeed do I claim the use of any two of them, if unaccompanied by any or either of the others;

but I do claim as my invention the exclusive use of the threefold combination of the sufficient quantity of metallic surfaces, the sufficient quantity of cold water passing among them, and the sufficiently capacious air-pump, as hereinbefore fully described, whether the said threefold combination be used alone or combined with the distilling apparatus and the steam saver, or either of them; I also claim the exclusive right of combining the distilling apparatus and the steam-saving apparatus, or either of them, with the abovementioned threefold combination, or even with the two first of them, *videlicet*, the metallic surfaces and cold water passing among them, should a less air-pump be used. In witness whereof," &c.

148. *Mr. Hall's Patent Condenser.*—The annexed figure represents a section of one of a pair of marine engines, adapted to the "Hercules," of 180 horse power, with Mr. Hall's patent improvements applied to them. The steam from the working cylinder enters the upper chamber *a* of the condenser, which communicates with the lower chamber *f*, by means of numerous pipes *b b* contained in the cistern *c c*. These pipes are surrounded by cold water in the cistern *c c*, which enters at the opening *d*, and flows off at the opening *e*. The air-pump is seen at *g;* by means of the air-pump, the water resulting from the condensation of the steam in its passage through the pipes *b b*, together with the air and uncondensed vapour, is drawn off from the condenser. The feed-pipe is seen at *h*, by which the water is conveyed from the air-pump to the boiler. In order to ensure an equal distribution of the steam amongst the pipes *b b*, a plate *k k*, perforated by numerous small holes, is fixed in the upper chamber *a*, at a short distance from the orifices of the pipes.

149. *Mr. Hall's Distilling Apparatus.*—The figure at page 216, represents a longitudinal section of Mr. Hall's improved apparatus for replacing with distilled water any loss arising from leakage of water or waste of steam, so as to maintain the water in the boiler constantly at the same

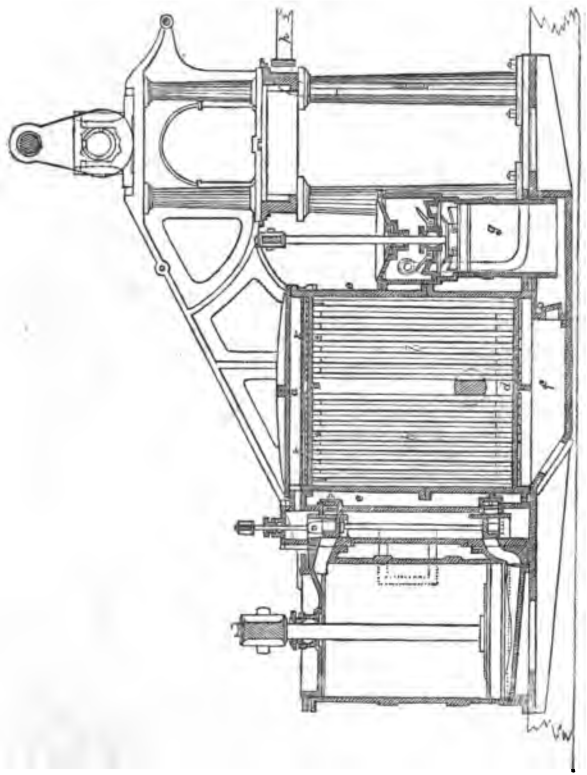

Fig 80.

height. A metallic box *a a* forms the upper part of the apparatus; *b b* is a smaller box, suspended from the former by rods *c c*, at the angles of the boxes; *d d d* are a series of copper pipes of about one inch internal diameter, open at each end, and passing through holes in the plate of the box *a a*, and also through holes in the plate of the box *b b;* these holes are enlarged to receive a tape washer, which is screwed into close contact with the copper pipes by means of a brass ring or ferule, so as to form a steam and water-

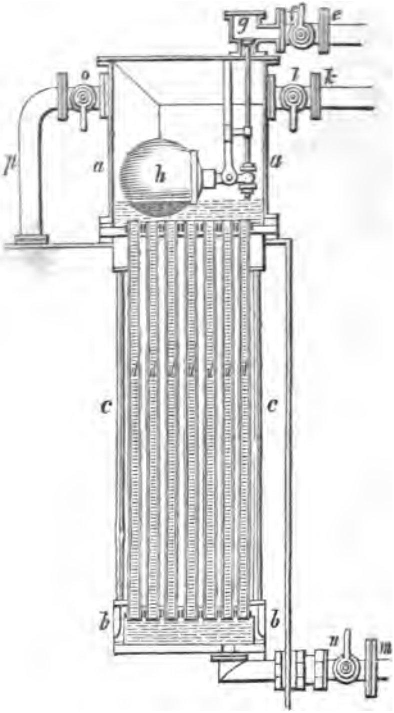

Fig. 81.

tight joint, in the same manner as the joints of the pipes of the condensers are made. By this arrangement of tubes, a very extensive metallic surface is obtained in a small compass, for transmitting heat from the water or steam within the boiler, to the water intended for the purpose of distillation *in vacuo*. The metallic box *a a* is connected with the upper chamber of the condenser by the pipe *k*, by which means a vacuum more or less perfect is created within the distilling vessel, according to the condition of the vacuum produced in that chamber; hence the water will boil at a lower temperature than 212°, and evaporate more rapidly than if exposed to the pressure of the atmosphere. To regulate the supply of distilled water, so as to maintain the water in the boiler at the proper height, a cock *l* is placed between the pipe *k* and the distilling vessel; when the water in the boiler falls too low, the cock *l* is to be opened in order to allow the distillation to proceed; the steam from the distilling vessel passes into the upper chamber of the condenser, and the distilled water resulting therefrom is conveyed to the boiler along with, and in addition to, the water produced by the condensation of the steam used in working the engine; and, when the additional quantity of water thus returned by the air-pump to the boiler has restored the water to its proper height therein, the cock *l* is to be closed, and the distillation stopped. The distilling vessel is connected with the cold water cistern by the supply pipe *e*, to which is fitted a cock *f*, and the water is maintained at the proper height in the distilling vessel during the distillation by means of the float *h* and the valve *g*. In order to get rid of the impurities deposited in the course of distillation, a pipe *m*, fitted with a cock *n*, is inserted into the bottom of the distilling vessel, and another pipe *p* with a cock *o* communicates between the distilling vessel and the boiler; the operation is performed by closing the cocks *l* and *f*, and opening the cocks *n* and *o*: the pressure of the steam from the boiler acting upon the surface of the water in the distilling vessel, drives it out with its impurities through the pipe *m*. In the figure, the copper tubes and the box *b b* of the apparatus are represented as inserted in the boiler; but the whole of the apparatus may be placed on the outside of the boiler, if the pipes be surrounded by, or enclosed in, a casing, connected by pipes at the top and bottom with the boiler.

150. *Mr. Hall's Steam Saver.*—The following figure represents what Mr. Hall terms a *steam saver*, its office being to cause the steam which usually escapes at the safety valve, to enter the condenser, instead of passing into the atmosphere, so that the distilled water resulting from its condensation may be restored to the boiler by the action of the air-pump, or any other suitable means. A cylindrical vessel *a a*, closed at the top and open below, is plunged into mercury contained in a circular groove or cavity formed between two concentric cylinders *b b*, *b b*. These cylinders are supported upon a square box, which is closed at the bottom, and communicates with the boiler by the opening *c*, and with the condenser by the bent pipe *d*, to which latter is fitted a sliding valve *f*. The cylinder *a a* is loaded by the weight *g g* suspended within it, to which is attached the frame *h h;* the stem of the valve *f* is attached to this frame, and the stem of the valve *e* works freely in a hole in the frame, and has a nut at the upper end, at a small distance above the lower bar of the frame. The action of this apparatus is as follows: When the steam does not exceed the regular working

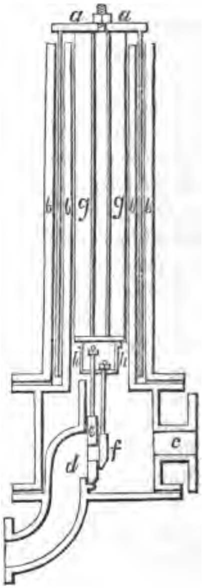

Fig. 82.

pressure, the valves remain in the position shown in the figure, the inverted cylinder being kept down by the weight *g g;* but when the force of the steam is sufficient to overcome the resistance of the weight, the inverted cylinder is raised by the pressure of the steam, and draws up first the small valve *f*, so as to open the aperture in the valve *e*, and allow a portion of steam to escape into the condenser; and as soon as the nut on the stem of the valve *e* rests on the frame *h h*, the continued ascent of the cylinder *a a* elevates both valves together, and uncloses the aperture of the pipe *d*, so as to offer a larger opening for the passing off of the steam. When the steam within the boiler is reduced to the working pressure by the requisite escape through the *steam saver*, the valves *e* and *f* descend along with the inverted cylinder *a a*, and close the openings.

151. *Comparison between Injection Steam Engines and Mr. Samuel Hall's Patent Steam Engines.*—

(1.) Injection engines, when applied to steam navigation, comprise of necessity the barbarous practice of supplying dirty and salt water to the boilers.	The patent engines effect a supply of the purest distilled water to the boilers, by which they are always kept in a perfectly clean state.
(2.) In injection engines the water in the boilers may become saturated with salt, in which case it will not boil under 225° of temperature.	The patent engine, having pure distilled water in the boilers, it boils at 212°, or at 13° less temperature than salt water, and of course requires less fuel to convert it into steam.
(3.) In injection engines, in order to prevent the water from becoming saturated with salt, a large quantity of boiling water must be pumped out of the boilers, or blown off, and replaced	The patent engine boiler never requires any blowing out, no matter how long the engines are in uninterrupted operation.

with cold water every two or three hours, which cold water, having to be brought up to the boiling point, causes a considerable waste of fuel to take place.	
(4.) In injection engines, the boilers will, after every precaution is taken, become coated with hard scale of considerable thickness; this being a bad conductor of heat prevents the free transmission thereof from the fire to the water, causes the boilers to burn and wear out very rapidly, and greatly increases the consumption of fuel.	The patent engine boilers will be perfectly clean, not only for many voyages, but for years, and their durability will be very much greater than that of boilers supplied with salt water, and a comparatively small consumption of fuel will also be the result.
(5.) In order to prevent the boilers of injection engines from burning and wearing out, with a rapidity that could not be submitted to, it is necessary in long voyages to suspend the working of the boilers, in order to empty and cool them, for the purpose of clearing away and chipping off the scale that firmly adheres to them, which operation considerably injures the boilers.	In the patent engines, all delays and inconveniences arising from the emptying and cleaning of boilers are entirely superseded, for by their permanent cleanness the water they contain entirely defends them from the action of the fire, and as no deposit takes place, they are not subjected to the injury caused by chipping off scale, as in injection engines.
(6.) In injection engines, the oil which is put into the cylinders, stuffing boxes,	In the patent engines, not a particle of the oil which is given to the internal parts

slides, &c., is speedily carried away by the injection water into the sea; the time, therefore, of its being in the engines is so short, that nine-tenths of it is wasted, and does but little, if any, good, and it does not, as in the patent engines, enter the boilers and protect them from the corrosive action of hot salt water.	of the engine, &c., is washed away into the sea, or lost, but it is all carried into the boilers, whereby they are protected from corrosion, and an ample lubrication of the engine is effected at scarcely any cost, as hereafter mentioned.
(7.) In injection engines, a portion of the salt contained in the water is carried over mechanically along with the steam into the working cylinders, slowly corroding and wearing the slides, valves, and other internal parts of the engines, whereby they are rendered untrue, and a considerable quantity of steam escapes past them, and is wasted.	In the patent engines, a portion of oil being always, as before stated, introduced in connexion with the pure water into the boilers, it passes over mechanically along with the steam in minute particles into the cylinder; thus, this ample lubrication actually improves the slides, valves, and other internal parts of the engines, instead of injuring them, whereby a great saving in their wear and tear is effected.
(8.) In injection engines, salt water, dirt, sand, and other impurities, pass through the air-pumps, and thereby render them and their piston-rods, &c., very rough and full of furrows, in consequence whereof great friction in working them, and	In the patent engines, nothing but distilled water and oil pass through the air-pumps, which, instead of becoming rough, are thereby rendered more smooth and polished; and, of course, brass buckets, piston-rods, and hinges to the air-pumps,

waste of power, are occasioned.

(9.) In injection engines, a considerable power is required to pump out the injection water; in engines of 450 horse power (like those on board the Great Western), 2700 gallons of water have to be pumped out of a vacuum (reckoning six gallons per horse power per minute), and this requires as much power as the pumping of that quantity of water out of a well, 30 or 32 feet deep.

(10.) In injection engines, in stormy weather and heavy seas, the condensing water enters the condensers as rapidly when they are going at a slow, as when they are going at a fast, speed; and, as it is impossible to regulate the quantity of injection water according to the irregularity of the speed of the engines, great danger arises, on the one hand, of choking the condenser and the air-pump, and of even breaking down the engines, by the admission of too much water when they are going slow, or, on the other hand, of deducting greatly from the are not necessary, as is the case in injection engines.

In the patent engines, the air-pump has only to pump out of the vacuum, the water resulting from the condensation of the steam, which in a pair of engines of 450 horse power is only about 50 gallons per minute; the saving of the power, therefore, required to pump out the 2700 gallons per minute of injection water, is so much additional effective power gained, and applicable to the paddle wheels.

The patent engines, in the roughest weather, and when the greatest power is required, preserve as perfect a vacuum, and consequently as great a power, as in fine weather; and all the care required in injection engines to supply the proper quantity of condensing water, is superseded, and the engineer is relieved from that onerous duty.

power of the engines, by injecting too little water into them when their speed is great, thereby deteriorating the vacuum, and reducing the power of the engines, and that at the time when the greatest power is required.	
(11.) In injection engines, the proper supply of water to the boilers is dependent upon, and entirely at the mercy of, the engineers, from whose negligence such serious accidents arise, as those of the explosion of the two Hull steam vessels, the "Union" and "Victoria," and many others, by which a most serious loss of life has taken place, and great injury has been done to the reputation of steam navigation.	In the patent engines, the boilers are never liable to be burnt down, or injured by the water becoming in them, by accident or by the carelessness of engineers, too low; for, as every cubic foot of water which is converted into steam is, by condensation, reconverted into precisely the same quantity, and returned to the boilers, the water is always kept in them at exactly the same height, *without any attention* on the part of the engineer.
(12.) In injection engines the vacuum is injured by the air which is in mechanical combination with the injection water, being conveyed by it into the condenser.	In the patent engines, a superior vacuum is obtained, owing to no air being introduced into the condensers, and to the condensation being more perfect than can be effected by injection.

152. *Advantages of Mr. Hall's Engines.*—

First;—From the various causes above mentioned, a saving of at least one-third part of the fuel is effected in the patent engines, or, in other words, injection engines consume half as much more fuel as the patent engines.

Second;—For every ton of coal that is saved, a ton of profitable freight may be substituted.

Third;—As vessels with engines to which these improvements are applied, make their passages nearly as quick in stormy as in fine weather, and as they do not require during, or at the end, of their passages, however numerous, any blowing out or cleaning of the boilers, to occasion delay, every such vessel is capable of making more passages, and of becoming in that ratio more profitable.

Fourth;—As boilers supplied with pure distilled water will endure a much greater length of time than those in which salt water is used, not only is the annual expense of the boilers greatly diminished, but the loss of the time of the profitable use of the vessel during the taking out of old boilers, and the replacing of them with new ones, is also avoided—to say nothing of the breaking up of the decks and other expenses attending the business.

Fifth;—As the internal parts of the engines are kept so much longer in repair, owing to the causes already mentioned, the perpetual expense and time required in repairing such parts is greatly diminished; indeed there is no doubt that the slides, valves, pistons, and all the internal parts of the engines, are in much finer condition, after having been in constant operation for years, than they are the first day they are set to work. The circumstance of salt being carried over with the steam into the cylinders (when salt water is used in the boilers) is unquestionable, as well as its being the cause of the valves, and other internal parts of the engine, becoming so soon in bad condition, whereby a great waste of steam takes place, even long before they become so very much worn as to render it indispensably necessary to give them a thorough repair.

153. *General Remarks on the foregoing Subject.*—1. The increased simplicity in working the patent engines may be more fully noticed. The regulation of injection water, and of the water to supply the boilers, now forms no part of the duty of the engineer, as they are quite superseded by no

injection taking place, and the boilers being self-supplied with undeviating accuracy. It need scarcely be added how important it is to the safety of vessels to have engineers fresh and untired in stormy weather, instead of being so jaded and fatigued as not to be able to perform their duty. 2. The comparative advantages of the patent engines are not so great on the first starting of new engines, or even during the first month or two; for then the boilers and machinery of injection engines are as clean, and in as good order, as those of the patent engines; but after that time, and when the boilers of the former become thickly coated with scale, and the internal parts of the engines are worn and galled, while those of the latter are actually improved, the comparison should be made. 3. It is quite certain that a vessel with the patent engines, of 300 horse power, will effect an increase of economy and advantages of £2500 or £3000 per annum over a vessel having injection engines of that power; consequently, the former will realize so much greater a profit. 4. Much has been said of the cost of these improvements; but the additional expense of copper boilers is at least double that of this apparatus; and it is agreed by all parties, that common engines must have copper boilers on board vessels intended for India, but that with the improved engines iron boilers will answer equally well, if not indeed in many respects better.

154. *Account of the "Queen" Steam Vessel.*—In consequence of a statement which appeared in several of the London papers in the month of November, 1841, to the effect that the "Queen" steam vessel, which was engaged in the late China expedition, "having Hall's condensers, was often out of repair," the following testimony of Mr. Lambert, late superintending engineer of the "Queen," must be highly satisfactory to Mr. Hall, and to every one who feels a just interest in the success of his undertaking. Mr. Lambert, in a letter addressed to the editor of a London paper, pledges his word that the statement is *untrue;* he is at a loss to conjecture who could be the author of so un-

founded a statement.—"It certainly was not the commander of the vessel, Captain Warden, for he was always as much delighted with the operation and effects of the condensers as myself, and particularly with that of keeping the boilers so clean, that we actually did not open them for examination for six months together, and upon one of these occasions, when Captain Warden was examining them, he exclaimed, that 'the boilers were as clean as if they had been cleaned out with a brush.' Nor could the statement in question come from any of the sub-engineers, for the immense saving of labour and trouble to them by Hall's condensers, renders the management of a pair of engines almost a sinecure in a hot climate, compared with that of injection engines. I must say, that I am astonished to find, on my return from India, that the patent engines are not universally adopted, especially for hot climates, where they obtain an extremely superior vacuum. We had on the 'Queen' a vacuum superior by 2½ inches to the average vacuum produced by other steamers, all circumstances in each being the same.

"I went out from England in November, 1839, as the Honourable East India Company's superintendent engineer of the above-mentioned war steamer (as already stated), and I remained in her while she was in India, and on her passage to Macao and Chusan, in China, until I was invalided from her in May, 1841, and I deem it no more than justice to the invention to declare, that during the whole period her engines were never out of repair, so as at all to interrupt her operations, although frequently engaged with forts, especially with those of the Bocca Tigris, and that Hall's condensers always acted in the most efficient manner; the boilers (as above intimated) being, consequently, at the time I left the vessel, as clean as when they were new; in fact, I assert that, with mere common attention, engines with those condensers are much less liable to get out of repair than those with the common condensers, while the former are beyond comparison safer than the latter, and relieve the mind of the engineer from his greatest anxieties, viz. the management of the injection and the working of the boilers, required by the latter. I have no hesitation, therefore, in assuring you, that the statement which I have quoted from the newspapers, viz. that the 'Queen,' on account of having Hall's condensers, is often out of repair, is as untrue as it is unjust to the patentee, and I am confident that Captain Warden, and the engineers who have experienced the comforts they have derived from these condensers, will corroborate my testimony.

"I may here, in conclusion, mention, that in May last, when at Calcutta, I went on board the steam-ship 'India,' and examined her engines, which have Hall's as well as the common condensers applied to them. They are fitted in such a manner that either of them may be used at pleasure, and the one can be exchanged for the other in a quarter of an hour's time. The superintendent engineer, Mr. A. Thompson, however, informed me, that the former condensers had acted in so satisfactory a manner from the time of leaving England, that they never in any one instance had to resort to the use of the common condensers, although that might have been so soon and easily done. This I conceive to be a sufficient proof that Hall's condensers acted as perfectly on board the 'India' as on board the 'Queen.'"

155. *Reports of the "Megæra" Steam Vessel.*—About four years ago, the steam vessel "Megæra" was fitted up with Messrs. Seaward's engines, and Mr. Hall's condenser, and proceeded to the Mediterranean. At first, so little was the principle of the invention understood, that *the boilers were actually filled with salt water (!); the steam was blown off into the atmosphere (!);* and, the water in the boiler being thus diminished faster than the still could supply it with distilled water, the *boilers were replenished with salt water (!),* running it through the still; &c. After this extraordinary mis-management, Mr. Hamshaw, the superintending engineer, undertook to ascertain whether the failure of the vessel arose from defect in the principle, or in

the management, of the condensers. In a letter, dated from Malta Yard, Sep. 19, 1838, he observes:—"The first thing I attended to, was to the action of the still, to ascertain whether it distilled sufficient water for the boilers (provided the steam was not blown off), and also whether the water was free from salt, and *both results were satisfactorily proved;* for in the space of nine hours a considerable increase of water took place in the boilers; and I have not the least hesitation in saying that, provided Mr. Hall's improved engines were properly managed, they are *the most complete equipment of marine machinery that has ever been fitted to a steam vessel.*"

The following extracts, taken from the government "Reports," of the performance of the "Megæra," for the month of January, 1840, fully justify the opinion of the engineer above stated. "In every respect, and on every point, the performance of the vessel has been most satisfactory. Whatever inefficiency exists, is to be attributed to a want of power in the engines. After two years' almost constant work, we can speak favourably of the general construction and efficiency of the engines. The power of the several parts of the engines appears to be well-proportioned; if any exception is to be made, it may be that the cold water pumps attached to Hall's condensers are not of sufficient power. This remark, however, must not be interpreted to the disadvantage of *the condensing apparatus, than which nothing can be more satisfactory and beneficial to Her Majesty's service,* the best proof of which is the present very fine condition of the interior of the boilers. These, when examined in October last, presented as good an appearance as when first put in place two years ago." A similar report of the performance of this vessel was made in June, 1840. The water had been recently blown out of the boilers, *where it had been since October last,* and *the interior was found in the highest state of preservation.* In August, 1840, it is stated, that the engines were at work upwards of 500 hours during that month, and were in every respect efficient. In August, 1841, the report states that the performance of the vessel was in every respect satisfactory, except as to speed. A similar report was made in September.

156. *Reports of the "Volcano" Steam Vessel.*—The "Volcano" was built and equipped at the same time as the "Megæra," and by the same manufacturers, the Messrs. Seaward, of Limehouse. The "Megæra" was furnished with the patent condenser of Mr. Hall, the "Volcano" with common injection engines. The monthly reports of the performance of the latter vessel, from February to September, inclusive, for the year 1840, are favourable:—"The engines are well constructed, and the bearings well adjusted, and are in good repair, and would no doubt answer very well for some years to a vessel of 500 tons. Had she power equal to 1-3rd of her tonnage, would be a very efficient vessel; but, with her present power, will not steer, blowing hard, against a heavy head sea. The boilers will, no doubt, last well for seven years, with the addition of new side plates to the fireplace." In November, 1840, it is stated in the monthly report that the pipes are generally defective, viz. blow-off pipe, injection pipes, bilge pipes, blow-through pipes, &c. The boilers appear, also, to have been out of repair at this time. A survey was accordingly held, and the boilers were found so defective in the take-ups as to require to be sent to England for repair. The vessel was accordingly sent home for repair in January, 1841. It is right, in giving these brief notices of the performance of two vessels, fitted up on a different plan of condensation, to add that the boilers of the "Megæra" were made of iron, those of the "Volcano" of copper. How far the comparison between the performance of the two vessels may be affected by this circumstance, remains to be decided.*

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* For the "Reports" of the two steam vessels, above noticed, the author is indebted to the courtesy of the Lords Commissioners of the Admiralty, who afforded him every facility for obtaining the information he desired.

157. *Voyage of the "British Queen."*—The "British Queen," the noblest vessel ever constructed for Transatlantic navigation, was provided with Mr. Hall's patent condensers. By reference to the engineer's log of this ship, during her fourth voyage from New York to London, it appears that the mercury in Bedwell's patent barometer, affixed to the engines of the vessel, stood steadily at 30½ inches. Mr. Peterson, chief engineer of the "British Queen," observes:—"The extraordinary vacuum produced in these engines is unrivalled by any engine or engines in the world. I believe it impossible for engines on the common plan of condensation to produce a vacuum any thing like this. The vacuum, indeed, in the best sea-going injection engines, *averages* only 27½ inches, and the fastest river boat on the Thames never yet exceeded it. The great *increase of power*, derived from the use of the patent condensers, is therefore self-evident. Having had the charge of another pair of engines, fitted with Mr. Hall's condensers, viz. those of H. M. S. V. 'Megæra,' made by the celebrated firm of J. and S. Seaward and Co., and having experienced nearly the same result, I feel I should not be doing Mr. Hall justice if I did not express my firm belief, that if all the vessels in which his condensers were fitted had been properly managed and understood, the same successful results would have been the consequence. I have only mentioned the *increase of power* derived from Hall's condensers; but the numerous other advantages derived from their use are so well known, as scarcely to require repetition—the cleanness of the boilers, the fine condition of all the internal working parts of the engines, &c., and owing to the use of the distilled water only. The 'British Queen' went from London to New York, last voyage, and returned to London, *with the same water in her boilers, and without the least addition of water even to start with.* In fact, the boilers were not opened from the time of leaving London until her arriving there again, when the water was perfectly pure. I have never, in fact, seen any boilers so clean, and so free

from deposit of any sort. It is worthy of remark, that Mr. Hall's beautiful plan of distilling *in vacuo*, not only supplied all occasional waste of water, arising from steam escaping from the safety valve, &c., but also furnished a large quantity of distilled water for the ship's use." The dimensions, power, and performance, of this incomparable vessel are the following:—length from figure-head to taffrail, 275 feet; length of the upper deck, 245 feet; breadth between the paddle boxes, 40 feet; breadth over all, 61 feet; depth of hold, 27 feet; diameter of paddle wheels, 31 feet; diameter of engine cylinder, 6 feet 5½ inches; length of stroke, 7 feet; power of engines, 500 horses. This vessel left Portsmouth on the 2d of March, 1840, at 12-40 p. m., and arrived at Sandy Hook on Wednesday, 18th March, at 10 a. m.; total number of revolutions, 291,850; coals consumed, 635·4 tons. She left New York on the 1st of April, 1840, at 2-30 p. m., and arrived at Spithead on Thursday, 16th April, at 6 p.m.; total number of revolutions, 263,400; coals consumed, 613 tons 16 cwt.*

158. *Howard's method of generating Steam.*—A new method of generating steam was introduced a few years ago by Mr. Thomas Howard. The novelty of this plan consists in the production of steam from the smallest possible quantity of water on a small surface, and this, *without the use of a boiler*. The advantages proposed by this contrivance are, considerable economy of fuel, reduction in the weight of the machinery, diminution of the space allotted to flues, absence of smoke, and avoidance of deposit and incrustation. Mr. Howard observes, in the specification of his patent, that in the ordinary method of generating steam by means of boilers, a body of water is exposed to a large surface of metal, from which it receives a comparatively low degree of heat; and

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* The dimensions of the unfortunate "President" varied in no great degree from those above given; her cylinder had a larger diameter, and there was a greater length of stroke. The power of her engines was that of 600 horses.

that, as the temperature of water bears a constant relation to the density or pressure of the steam (page 126), the rapidity of evaporation is thereby limited. In the new process of vaporization, the power of the engine is derived from the generation of steam from the least possible quantity of water on a small surface, heated to and maintained at such a temperature (about 400° Fahr.) as will vaporize the water with the utmost rapidity; the steam so formed having a high temperature, but relatively a low density or pressure, and being, therefore, capable of parting with more or less of its heat without undergoing condensation. The surface exposed to the fire is preserved from the injurious effects of a strong local heat, by the interposition of mercury; while the vaporizing surface is preserved from deposit by the continued use of the same water, as in Mr. Hall's apparatus. In Mr. Howard's engine, alcohol, or other liquids, may be substituted for water. In describing this apparatus, the mode of generating the steam will first be explained, and then the method of producing a vacuum by condensation.

(1.) The *mode of generating the steam* is as follows. A plate of wrought iron is placed horizontally over a fire of coke or anthracite coal, the combustion of which is regulated by a blowing apparatus; the surface of the plate exposed to the fire is about three-fourths of a square foot for each horse power of the engine. A second plate is fixed above this, at a distance of about three inches, and firmly secured to it by means of a strong ring of corresponding depth, to which the circumferences of both the plates are tightly bolted. The surface of the upper, or vaporizing, plate is increased to about four times that of the lower, or fire plate, by the insertion of shallow cups of about two inches in diameter throughout its entire surface; the cups are open above, and closed below, where they dip towards the lower plate. The intermediate space between the two plates is filled with mercury. The temperature of the mercury should never be allowed to rise above 500° Fahr., nor to fall below 350°; the combustion of the fuel is regulated for the purpose of maintaining the due temperature. Upon the upper plate is projected, at intervals, by means of a pump, a nozzle, and a valve, a small quantity of water from a hot water cistern; this water is instantly converted into steam of very high temperature; the steam is conducted into a chamber surrounding the working cylinder, where it receives additional heat from the hot air of the flues which circulates round this chamber; the steam is then directed to the cylinder valves in the usual way. This apparatus is expressly intended for working the steam *expansively*, the pressure being generally about ten pounds on the square inch above that of the atmosphere, and the steam cut off from the cylinder at about a third of the stroke.

(2.) The *process of condensation* is as follows. The steam is conveyed from the cylinder, by means of an eduction pipe, to the condenser, as in the common engine. A jet of distilled water, from a vessel purposely provided, is allowed to play into the condenser, by which means the steam is condensed, and mixed with the distilled injection water. This warm liquid is pumped out of the condenser in the usual way; it is then cooled by being conveyed through a copper worm of many coils, which is immersed in cold water, and terminates in the vessel of distilled water; it thus serves to supply the demand for injection. By entirely filling the worm, and partly filling the hot water cistern, before the engine starts, a sufficient quantity of water is provided for circulation. A still is employed for supplying any waste of water, caused by leakage, and is attached to the flue of the vaporizer. An apparatus of this kind was fitted, in 1835, to the government steam vessel *Comet*, which, in a trip from Falmouth to Lisbon, consumed only one-third of the amount of fuel required by this vessel when worked by the common engines; the consumption with Mr. Howard's engine being less than 250 lbs. of coke per hour, whereas with the common engines it amounted to about 800 lbs. per hour. Mr. Howard's mode of condensation may obviously be applied with equal success to the common engines provided with boilers. The principle of Howard's engine has been noticed at page 33.

159. *Of the Valves and Eccentrics.*—The several kinds of valve attached to steam cylinders, and the mode of working the valves by eccentrics, have been fully described in chapter VII. 1. It is important that the *valves*, and the passages connected with them, should be of considerable size, for the velocity of the piston is obviously proportionate to the steam apertures; when these are of sufficiently large dimensions, the speed of the piston may be increased to 500 feet a minute. The usual allowance for the dimensions of the valves and passages leading into the cylinder is 1-25th of the area of the cylinder; those leading into the condenser should be larger in cases of great speed: they have been made 1-12th and 1-10th of the area of the cylinder. The valves usually employed in marine engines are the long D-slides of Murdock, and the four-port slides of Messrs. Seaward, already described. 2. The position and action of the *eccentric* may be readily understood by referring to the figures at pp. 120 and 208. The former figure represents an eccentric; the latter, all the moving parts except the eccentric; the imagination of the reader will suggest the mode of adapting the former to the latter. If the position of the eccentric, as seen in fig. 58, be supposed to be inverted, its point N applied upon the point *a*, or axle, of fig. 78, and the series of levers *l h* connected with the slide valves attached to the side of the cylinder, as in figures 2 and 4, of the plate, page 165, it will at once appear how the rotatory motion of the shaft of the steam vessel communicates, by the intervention of the eccentric, a reciprocating motion to the slide valves of the cylinder. The eccentric is shown *in situ* in the engraving of the marine engine. (See Frontispiece.) It is generally placed loosely on the shaft, so as to admit of its working the valves in the forward and the backward direction. 3. The nice *adjustment of the slides* is an essential point; they should not open and close the steam passages of the cylinder precisely when the piston is at the

termination of its stroke, but a little before this period; more time is thus allowed for the condensation of the steam, and the production of a better vacuum, and the advantage is gained of working the steam expansively within the cylinder. 4. An apparatus of the following kind is generally employed for cutting off the steam at certain periods of the stroke, so as to allow the steam, already introduced into the cylinder, to work *expansively*. The steam tube S S, proceeding from the boiler, is furnished with a valve V, placed at some part of the tube before it opens into the valve-case; the spindle of the valve passes through a stuffing box, and is raised and depressed by means of a series of levers, two of which are seen at *d d*. A represents the paddle shaft, upon which are fixed two projecting parts, or cams, *a a*, the breadth of which is proportioned to the extent of the stroke which is cut off. As the shaft revolves, these projections act upon a pully *b*, which is pressed closely to the shaft by the weight *w*. From the position of the levers, and the connecting-rod *d c*, it is evident that the valve V is opened and closed twice during each revolution of the shaft.

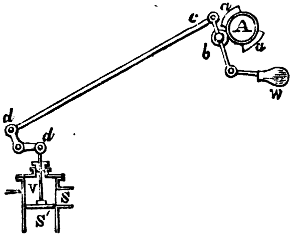

Fig. 83.

160. ***Recent modifications of Engines.***—Messrs. Maudsley and Field have recently introduced some modifications in the construction of the steam engine, with the view of bringing the *expansive* principle of steam into more ex-

tended operation. In order to effect this with steam of low pressure, it is necessary to increase the area of piston surface upon which the expansive force of the steam acts; this object is obtained either by enlargement of the cylinder, or by the adaptation of two cylinders to one engine; both of these plans have been made the subjects of a patent by Messrs. Maudsley and Field. 1. In the engine with the *enlarged cylinder*, there are two piston-rods, connected at their upper extremities by a cross bar; to this cross bar is attached the connecting-rod, which drives the crank on the paddle-shaft; the paddle-shaft is situated above the cylinder, but below the cross bar which connects the two piston-rods. 2. In the engine with *two cylinders*, the two piston-rods are connected at their upper extremities by a cross bar; to this is fixed an axle which is driven upwards and downwards between the cylinders; to the lower part of this axle is attached the connecting-rod, which is driven up and down with the axle, and which at its upper extremity drives the crank of the paddle-shaft; in this engine, the paddle-shaft is situated above the cross bar which joins the piston-rods. 3. Mr. Francis Humphry obtained a patent for a new kind of engine, which has been fitted to the steam packet Dartford. By this mode of construction, the connecting-rod which works the crank is attached at its lower extremity to the piston itself; hence, *there is no piston-rod*, but, instead of it, a steam-tight case, which is permanently attached to the piston, and works up and down with it in the cylinder; the connecting-rod passes up through an aperture in this casing, and is attached at its upper extremity to the crank.

OF PADDLE WHEELS.

161. *Common Paddle Wheel.*—At each extremity of the shaft of a marine engine is placed a wheel, by the revolution of which the vessel is propelled. The wheel may be regarded as a series of *levers*, arranged in a circle, and brought suc-

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cessively into action; each lever consists of a radius, or arm, proceeding from the centre, and terminating in the circumference, of the wheel, where it is attached to a paddle board, or float; the *fulcrum* is obtained by the reaction of the water upon the paddles ; the *resistance* to be overcome is that of the water opposed to the progress of the vessel, and acting on the centre of the wheel; the *power* by which the resistance is to be overcome, is applied by the cranks of the engine upon the shaft which connects the centres of the wheels; by the action of this machinery, the vessel is propelled in the opposite direction to that in which the paddle-boards, or levers, revolve. The outline of the paddles is commonly rectangular, though Tredgold considers that the parabolic form would be advantageous, by securing an equal resistance with less breadth; that by this form the resistance to the paddle is least when it strikes the water obliquely at its first contact with this medium; and that the resistance increases as the action of the paddle becomes more direct. It is evident, by the most superficial observation, that *a considerable amount of force is lost by the position of the paddles on the wheel:* these boards, being placed on the circumference of the frame, in a plane which passes through the axis of the wheel, strike the water obliquely on entering it, and lift a considerable quantity of water on quitting it; both of these actions occasion a loss of power, the action of the paddle being direct only when it is in a position exactly between these points, or, in other words, when it is in a vertical line below the axis, or at the lowest point of the wheel. This will be rendered obvious by the following diagram. A B represents the water line, and C D F three of the paddles. Of these, D is acting in a *horizontal* direction, and is at the point of useful effect; but C, which is now entering the water, is at an oblique angle to the horizontal motion of the vessel, and will continue to be oblique, though in a decreasing degree, until it reaches the position of D; at the same time F, from the moment of its receding from the position of D, has been moving in a direction more and more oblique, and is now throwing up water, which it projects towards the stern of the vessel. Here, therefore, are

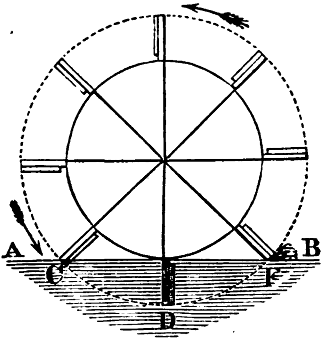

Fig. 84.

two causes of loss of power—the one termed the *oblique action*, the other the *back water*. Another disadvantage resulting from the oblique action of the paddles, is the *shock* which they experience on entering the water,—a point of time when the resistance is the greatest, and the useful effect of it the least. Other inconveniences arising from these successive shocks, are, the intermissions occasioned in the equable action of the wheel, and the tremulous motion or vibration communicated thereby to the vessel. These are serious defects in machinery constituting the immediate means of propulsion, and have hitherto baffled the ingenuity of inventors to provide a remedy for them; for it is evident, that the paddle wheel is extremely liable to injury, and frequently under circumstances which preclude the possibility of repairing the complex contrivances which have from time to time been suggested as improvements on the common form of paddle wheel.

162. *Field's Cycloidal Wheel.*—In 1833, Mr. Field, of the firm of Maudsley and Field, constructed a wheel with *fixed*

paddles, the object of which was to diminish the loss of power arising from oblique action and back water. The inventor describes it in the following terms:—"Each board is divided into several parts, or narrower boards, and arranged in, or nearly, such cycloidal curves, that they all enter the water at the same place in immediate succession, thus avoiding the shock produced by the entrance of the common board, so unpleasant to passengers, injurious to the vessel, and wasteful of the power. As the acting face of each board is radiating, it propels while passing under the centre in the ordinary way, and when it emerges, the water escapes simultaneously from each narrow board, and consequently cannot lop-up." This form of wheel has also been termed the *split paddle* wheel, from the division of its float into several parts; the number of these parts was at first six or seven, but it has been reduced to only two, every reduction having been found to be attended with advantage; in its most reduced state, its form is not far removed from that of the common wheel. The following figure exhibits the construction of the *cycloidal wheel*, as fitted to the Great Western steam ship by Messrs. Maudsley and Field. The split paddles are placed on the arms of the wheel in the direction of the curve *a b*, which is a portion

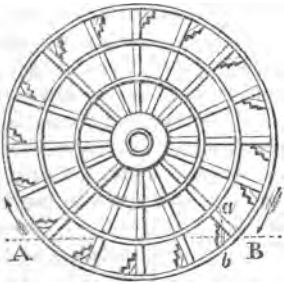

Fig. 85.

of a simple cycloid; the several parts of the paddle must therefore enter the water at the same spot, and in the same direction; in other words, they enter the water in a *curved* direction, by which means the shock and the resistance of the common float are prevented. When immersed in the water, the several parts no longer follow each other, but act as so many small independent radiating paddle boards. On emerging from the water, the motion of the several parts is still independent of each other, and the water is thrown off without the violence produced by the common paddle board. Mr. P. W. Barlow states, that this wheel enables an engine in any weather to make a greater number of strokes than a common paddle wheel, by throwing more work on the bottom paddles; that it reduces considerably the shock on entering the water; that it occasions less loss of power than the common wheel; and that it may always be employed beneficially. On the other hand, Mr. Mornay concludes, "that the shock received by the floats on entering the water must be reduced nearly to that of the outer board, but that this advantage is gained at the expense of a considerable portion of the effect, in consequence of which the wheels must require a greater surface of paddle board than common wheels. There may also be a little advantage in the manner the floats leave the water, but that, if any, must be very trifling. It is evident, that no theoretical calculation can be made of the effect of this wheel, its action being precisely similar to that of the common wheel, except that all but the outer boards move during a considerable part of their stroke in troubled water, whereby a loss of resistance is sustained, the amount of which cannot be computed. It remains, therefore, to be decided by experience, whether the disadvantages of this wheel are overbalanced by the advantages which it seems to possess."*

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* See two excellent papers on "Paddle Wheels," by Messrs. Barlow and Mornay, in the Appendix to Tredgold.

163. *Buchanan's Paddle Wheel.*—To obviate the objections arising from the fixed paddle, various contrivances have been adopted in order to preserve it in a vertical position during its progress through the water. A paddle constructed on this principle, must enter, and quit, the water edgewise, by an action similar to that of *feathering* with oars, and must necessarily have a motion of its own, independently of that which it receives from the wheel, so as to enable it to maintain a constant vertical position, while the wheel is performing its revolution. One of the earliest inventions of this kind was made by Mr. Robertson Buchanan, in 1813. The paddles were made to turn on horizontal axes or spindles, so as to maintain the vertical position during the entire revolution of the wheel; there was, consequently, no oblique action; but, during the first and last portions of their stroke, the paddles strike upon the water with their front surfaces, occasioning an additional resistance to the progress of the vessel. Buchanan's wheel has never been brought into use.

164. *Morgan's Paddle Wheel.*—In 1829, a patent was granted to Mr. Galloway, and sold by him to Mr. William Morgan, for a wheel constructed with feathering floats. This was the first successful experiment of vertically acting paddles; various improvements have since been added, and Morgan's wheel, as it is generally called, is now extensively employed both in government and private steam vessels. By this mode of construction, the floats are made to enter, and to quit, the water at any angle which may be required by the relative speed of the wheels and of the vessel. The principle of this machinery may by illustrated by the following diagram. The wheel consists of two sides or frameworks made of iron, the circumference of which is *polygonal*, having as many angles as there are paddles; the *inner frame*, or polygon, is attached to the shaft of the engine, which is not continued beyond the side of the vessel; the *outer frame*, or polygon, works on an independent centre attached to the paddle-box, and derives its motion entirely

from connexions formed between the two frames by means of spindles firmly keyed to both at the angles of the polygon; the space between the two frames is perfectly free.

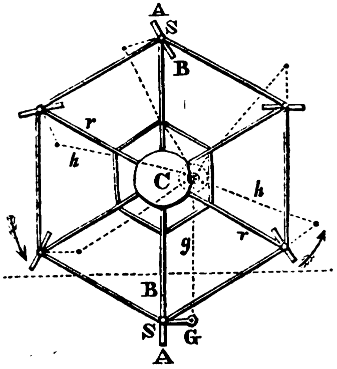

Fig. 86.

The frames are rendered compact by the addition of one or more polygons, placed between the circumference and the centre; one of these is seen in the diagram. C represents a section of the shaft and is the centre of the *inner polygon;* the circle described around C is a boss, in the circumference of which are keyed the arms, or radii, *r*, *r*, which extend to the angles of the polygon. F is the centre of the *outer polygon*; this centre projects in an inclined direction, like a crank, into the space between the two frames, and terminates at a point which is considerably *eccentric* with the wheel; the dotted circle described about F is a revolving collar or boss, to the circumference of which are fixed *guide rods*, *h*, *h;* these are jointed to short rods G S, called *stem levers*, which are fixed to the paddles B S A at any required angle. (One of the guide rods *g*, instead of being jointed, is keyed to the revolving collar or boss, in order to communicate to the collar the revolution of the wheel; this rod is therefore called the *driving rod.*) On attentive consideration of this mechanism, it will be seen that, in consequence of the eccentricity of F, the paddles will assume different positions, during their revolution, so as to differ very little from the vertical wheel, at that point of their immersion where their useful effect is applied. The comparative velocities obtained by *Morgan's wheel* and by the *common radiating wheel*, were tested by experiments made on some government vessels at Woolwich, the results of which are stated in Mr. Barlow's paper, already alluded to. The "Firebrand" steamer was fitted with a pair of engines of 70 horse power, and with common wheels, each of which had 14 paddles of 18 square feet area; the speed was 10·15 miles. The same vessel was afterwards fitted with a pair of engines of 60 horse power, and with Morgan's wheels, each of which had 9 paddles of less than 13 square feet area; the speed was 10·55, being *an increase of four-tenths of a mile with one-seventh less power.* The use of Morgan's wheel, as compared with that of the radiating wheel, is attended with the further advantage of economy of fuel. Experiments have also been instituted to determine the respective merits of Morgan's wheel, and Field's cycloidal wheel; the results were in favour of the former. The testimony of Captain Austin, who commanded the steam frigate "Medea" during her late service of four years, is highly satisfactory: he states that, whether at light or load draught, in smooth water or high sea, he found the action of her wheels (Morgan's) to be uniform, causing but very little, if any, tremulous motion of the vesssel, or jerk to her engines; and he considers that a vessel furnished with these wheels would be fully able to continue her service for *any* period (with the mechanical powers they might possess in the engine department) that her engines might enable her to do.

165. *Loss of Power by deep immersion of Paddles.*—There are two circumstances which materially affect the power of an engine: these are, deep immersion of the vessel in the water, and stress of weather. The former of these retarding

causes must always be in operation in the commencement of long voyages, when the vessel, being laden with a large quantity of coals, is necessarily deep in the water, and the wheel is consequently more immersed; the results are, increased resistance, increased oblique action, and a diminished number of strokes. The latter cause may operate at any period of the passage. Under either circumstance, it is evident that the engine is incapable of exerting its full power: if, for instance, a pair of engines, making twenty strokes per minute, be constructed of 500 horse power; and if, from either of the above causes, the number of strokes be reduced to ten, which is of no uncommon occurrence, half the power of the engines is lost, and the vessel is placed in the unfavourable condition of carrying engines of a considerable size, weight, and value, with an incapacity of exerting more than half their power. It has been stated, on good authority, that the largest pair of engines now in operation are frequently reduced in their speed from eighteen to six and a half strokes per minute, thus performing the duty of only 195 horse power instead of 540 horse power; and that this reduction of power generally takes place when the greatest possible power is required to contend against the mighty power of the ocean, and to enable the vessel to move, in spite of this resistance, away from the lee shores, rocks, and other dangers, instead of paddling away, nearly in the same place for hours, without making the least progress on her voyage, as is the case with the deeply immersed and unalterable common paddle wheels.

166. *Mr. Hall's patent Reefing Paddle Wheel.*—To obviate the inconveniences, above mentioned, several patents for a *reefing paddle wheel* have been successively granted to different engineers; these contrivances have, however, failed, chiefly from the want of simplicity in the machinery for moving the paddles, and the rapid corrosion of the moving parts by sea water. Mr. Samuel Hall, whose talent and ingenuity have been so successfully applied to various improvements in the steam engine, has proposed a simple and

effective plan for accomplishing this object, by which scarcely any more parts are exposed to corrosion than in the common paddle wheel, and by which, on the mere application of a hand lever, the power of the engine will, in less than a minute, without regard to weather, withdraw the whole of the paddles from the extremity close up to the boss of the wheel, or to any intermediate distance to suit the immersion of the vessel. This contrivance is not, however, confined to merely regulating the paddles, as above described, but admits of their being withdrawn entirely out of the water, or as nearly so as possible, when desirable to do so—as, for instance, when the wind is so favourable as to render it desirable that the vessel should proceed entirely under her canvas, and that the working of the engines should be discontinued; and, when that is no longer the case, of the paddles being returned to their proper situations in the water, for the renewed operation of the engines. A pair of Mr. Hall's Reefing Paddle Wheels of 14 feet diameter were subjected to experiment nearly a month, on board a new iron steam barge, the "Lee." The barge went from Blackwall to Rochester Bridge in 7 hours and 18 minutes, being empty, and drawing only 2 feet and 9 inches of water. On her return, she was deeply laden, and drew 5 feet 6 inches of water; she performed the same distance in 7 hours and 51 minutes, being, by means of the reefing wheels, only 33 minutes longer in doing so when deeply laden, than when empty. This experiment proves how important it is to employ reefing paddle wheels in vessels destined for long voyages, during which the immersion of the wheels in the water is necessarily subject to great variations of depth. Among the numerous advantages of these wheels, two may be here mentioned: viz. first, the instantaneous manner in which a steamer may, by them, be converted into a sailing vessel, and *vice versâ;* whereby the whole of the fuel expended during favourable weather is saved, being probably, upon an average, upwards of one-third of the whole consumption; and, secondly, the reducing of the time very considerably (one-third, it is supposed, at least) now required for performing long voyages.* The testimony in favour of this contrivance, given by Mr. Hawksley, Civil Engineer, is complete: first, it is extremely simple; secondly, it is strong; thirdly, it is generally applicable; fourthly, it is durable; fifthly, it may be entrusted to the management of men of the commonest capacity; and, lastly, it is comparatively inexpensive.

ENGINES OF THE STEAM PACKET "RUBY."

167. *Dimensions and Speed of the Engines.*—The engraving which forms the *frontispiece* of this volume represents an elevation of one of the engines of the steam packet "Ruby," copied from Tredgold's atlas of plates. This celebrated vessel was built by Mr. Wallis, of Blackwall, in 1836, from the designs and specifications of Mr. O. Lang, Jun., of Her Majesty's Dock Yard, Woolwich; her engines were made by Messrs. Seaward & Co.; the packet belongs to the "Diamond" Company, and plies between London and Gravesend, between which places it has run four times a day for six months, making 48,600 miles—a feat which had never been equalled; the "Ruby" has, in fact, enjoyed the reputation of being the fastest boat in Europe, and perhaps in the world. The engines of this packet are of 50 horse power each; their weight, including the water in the boiler, is 90 tons, 5 cwt., being about 18 cwt. to the horse power; the diameter of the cylinder, 40 inches; length of stroke, 3 feet 6 inches; number of strokes per minute, 30; diameter of paddle wheel, 17 feet 6 inches; length of paddle board, 9 feet 2 inches, and depth, 15

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* *The Surveyor, Engineer, and Architect,* No. IV. The Author regrets that the limits of this treatise prevent him from fully *illustrating* this ingenious piece of mechanism. Those who are interested in the subject will be highly gratified by inspecting a beautiful model of it at the offices of the patentee, in King's Arms Yard, London.

inches; dip or immersion, 15 inches. The speed of the "Ruby" is 13·5 miles per hour, being about a mile more than had been performed by any vessel previously constructed. The pressure of the steam is only 3½ lbs. above that of the atmosphere.

168. *Remarks on the "Ruby" Steam Packet.*—The following remarks are gathered from the description of the engine of the "Ruby," given in the work of Tredgold. It is a remarkable fact, that this boat has not varied her speed 1-12th of a mile per hour; she has neither increased nor lost her speed; this has been particularly attributed to the use of the *patent slide valves* on board of this vessel, which after two years' working were found as perfect upon their faces as when first put together. A further proof of their superior working is evinced by the vacuum in the condensers of the engines having never varied 1-4th of an inch, having remained constantly between 28¼ and 28½. The *safety valves* are arranged on the plan of Boulton and Watt, a plan now generally adopted by the engineers of London; the engine man can open them at pleasure for the escape of the steam, but he cannot load them beyond the weight determined by the manufacturer, viz. 3½ lbs. on the inch; and it is remarkable that, with this small pressure, the "Ruby" has attained its great speed, while, in numerous instances, vessels working with high-pressure steam, and with the safety valves loaded at the pleasure of the engine men, have never been able to equal her speed. This clearly proves, what the late Mr. Watt demonstrated long ago, that *the most efficient, safe, and economical mode of working steam engines for marine purposes, is at a pressure of* 2½ *to* 3½ *lbs. on the inch.* In this and other respects, the "Ruby" is constructed on principles quite the reverse of those adopted by the Americans, who employ steam of very high pressure, with a very long stroke of the piston. The success of the "Ruby" is partly attributed to a most judicious arrangement in the *form and construction of the vessel.* From the method of *planking* which is adopted,

consisting of three thicknesses of oak placed diagonally and longitudinally, the vessel is completely trussed from end to end, and at once combines strength and lightness in an eminent degree. The *form of her bow* enables her to cut and divide the water, instead of gliding over it, as in the American vessels, her bow being shaped like a knife, and being as long on the keel as at the water's edge within two feet.

REFERENCES TO THE FRONTISPIECE.

A, Cylinder.
B B, Sway beams.
C, Cross head.
D, Main gudgeon.
E E, Side rods.
F, Fork head.
G, Connecting-rod.
H H, Cranks.
I I, Shafts.
K K, Side frames.
L L L, Condenser, hot well, and foundation plate, all cast in one piece.
M, Air-pump.
N, Feed-pump.
O O, Sleepers.
P, Crank pins.

a a, Steam nozle and valves.
b b, Eduction nozle and valves.
c, Steam pipe.
d, Throttle valve.
e, Handle and rod of throttle valve.
f, Starting lever.
g, Spill of steam valve.
h, Spill of eduction valve.
i i i i, Levers for working the valves.
k, Rod to connect levers.
l l, Parallel motion.
m, Snifting valves.
n, Blow-through valve.
o, Eccentric rod.
p, Eccentric beam and balance.

(1.) The *general mode of applying the steam* in the marine engine, including the action of the cylinder and its apparatus, the beam, the connecting-rod, and the crank, will be readily understood by referring to the figures, and the explanation of them, given in paragraph 145—to which the attention of the reader is particularly directed. The motion of the engine commences at the *cylinder* A. The piston-rod is supposed to be descending, and by means of the *cross head* C (corresponding to *f f*, in fig. 77) and two *side rods* E (corresponding to *f e*, in the same figure), it depresses the nearer ends of the beams B; these work on the *main gudgeon*, or pivot, D, and from their reciprocating motion are termed *sway beams*. The opposite ends of the beam ascend, and force a cross bar upward, to the middle of which is attached, by the *fork head* F, the *connecting-rod* G. The upper part of the connecting-rod is jointed with the *crank* H, by means of the *crank pin* P; and by the action of the crank the *paddle shaft*, I, is turned round.

(2.) By the reciprocating action of the further ends of the beams, the cross head of the *air-pump* M, and of the hot water, or *feed-pump*, N, is also raised and depressed, being furnished with an apparatus of side rods similar to those above described. Between these parts and the cylinder, are placed the *condenser* and *hot well* L L. The air-pump draws off the air and water from the condenser to the hot well, whence it is conveyed by means of the feed-pump to the boiler.

(3.) The motion of the piston-rod is regulated by a combination of rods *l l*, called the *parallel motion;* this has been already fully described (p. 52). The arrangement of the rods constituting the mechanism of this motion in the marine engine, differs in some respects from that adopted in stationary engines, but the principle is the same in both.

(4.) The steam is conveyed from the boiler, by the *steam pipe*, *c*, on the left of the engine, to the space *a a* which contains the *steam nozle* and *valves*, and through these to the top and bottom of the cylinder; the *spill of the steam valves* is seen at *g*. The supply of steam is regulated by the *throttle valve*, *d*, which is furnished with a *handle and rod*, *e e*. On the right side of the cylinder is placed the *eduction nozle and valve*, *b*, which is furnished with a *spill*, *h;* by this outlet the steam escapes from the cylinder to the condenser. The *snifting valve*, *n*, is on the left of the cylinders; its office has been already described (p. 29).

(5.) The valves are worked by the *eccentric*, *p*, by means of the *eccentric rod*, *o*, connected with the *series of levers*, *i i i i*, and the *rod*, *k*, which connects the levers together. The *starting lever*, *f*, enables the engine man to open and close the valves by hand, previously to placing them in connexion with the eccentric; by means of this hand gear, he is enabled to reverse the direction of the vessel.

(6.) The engine and boiler stand upon sleepers O O, which are generally made of African oak; the shaft of the engines is supported by the *side frames* K K. The valve at *m* is for the purpose of *blowing through*, a process which has been fully described (p. 203).

169. *Engines of the Steam Frigate "Gorgon."*—A very simple and light form of engine has been fitted to the "Gorgon," and some other steam vessels, in which the sway beams, side rods, and cross heads, are dispensed with, the piston-rod being connected with the crank by the mere intervention of a short rod. The annexed figure exhibits the machinery of this kind of engine. The rod *a* connects the upper part of the piston-rod with the crank pin, placed on the axle of the wheel; the axle is situated directly over the centre of the cylinder. The parallel motion of the piston-rod is effected by means of the fixed bars on each side; the same machinery serves to work all the pumps. The "Gorgon" has two engines of this kind, of 320 horse power; the diameter of the cylinder is 64 inches; the length of the stroke is 5½ feet; and the diameter of the wheel, 27 feet. The speed of this vessel has been 11¼ miles per hour, the number of strokes per minute being 19½, and the consumption of fuel 7 lbs. of coal per horse power per hour.

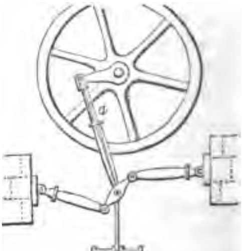

Fig. 87.

OF THE ARCHIMEDEAN SCREW PROPELLER.

170. *Mr. Smith's Propeller.*—The use of paddle wheels is attended with obvious disadvantages, viz. their projection from the sides of the vessel, their action for the most part out of the water, the impediment they offer to sailing by their interrupted action and the swell which they occasion on rivers and still waters, and their extreme liability to be disabled in naval warfare. To obviate these inconveniences, another mode of propelling vessels, of which smoothness and uniformity of motion are the most striking features, has been to a certain extent adopted. The immediate mechanism of motion in this plan is a spiral surface, or blade of iron, forming one turn of a *screw* A, and placed at an angle of about 40 degrees upon a cylindrical axis, which is fixed in a frame BB, inserted into the dead wood of the vessel. The axis passes through a stuffing box in the after part of the frame and stern of the vessel, and onwards to the engine, by which it is made to revolve. For every revolution of the crank shaft of the engine, the screw turns about 5½ times. The screws are moveable, and keyed on to the axis, so as to admit of the substitution of others of different sizes according to circumstances. The diameters of the screws are 5 feet and 7 feet, and their lengths 7½ and 8 feet. Since the establishment of the Ship Propeller Company, this apparatus, constituting Mr. Smith's propeller, has been fitted to several vessels. A war steamer, of 800 tons and 200 horse power, has been ordered to be constructed with the screw propeller,

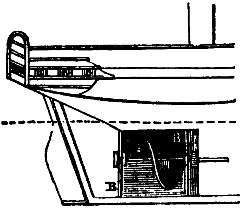

Fig. 88.

at Woolwich; a large steam ship is building at Bristol, of 3200 tons and 1000 horse power, under the superintendence of Mr. J. Brunel; another large vessel is to be built at Londonderry, of 1000 tons, and 400 horse power, for the Liverpool trade; the Archimedes experimental steam vessel is now plying on the Thames; and a large iron steam boat, upwards of 100 feet long, is now building at South Shields, for the Cowpen Colliery, fitted up with the Archimedean screw.

171. *Experiments of the Screw Propeller.*—1. The "Archimedes" steam vessel is registered at 240 tons, and is of 80 horse power. In 1839, this vessel circumnavigated the coast, and visited all the principal ports and harbours of Great Britain, sailing and propelling a distance of 2096 nautical miles; the time occupied in the various experiments and trials of the screw propeller being two hundred and thirty-seven hours and twenty-five minutes. 2. The "Princess Royal" steam vessel is of 101 tons burden, and 46 horse power. This vessel is intended for pleasure excursions from Brighton and the neighbouring towns and villages on the coast of the British Channel. The following report from the *Brighton Guardian*, dated June 16, 1841, accompanied with a certificate from the Committee of Management, evinces their confidence in the success of the project. "On Wednesday last, this newly-built pleasure boat, propelled by the Archimedes screw, made her first pleasure trip to Arundel and back, the party about 60 in number being the invited guests of the proprietors. The vessel was very recently built on the Tyne under the direction of Messrs. Bass, W. Catt, jun., and Collins, the committee of the owners, from which port she arrived on the 8th inst., in the short space of 48½ hours, the distance being upwards of 400 miles. She is of the following dimensions:—length of keel 81 feet, breadth of beam 17½ feet, depth of hold 10 feet, of immersion 6½ feet, tonnage 101 tons register. There are two engines each of 23 horse power, the screw is 5 feet diameter, 6 feet pitch, and 34 strokes of the engine, making 170 evolutions,

is the regulated speed. The velocity of the boat is about 8 knots an hour (equal to about 9¼ miles); but in our estimation its greatest recommendation as a boat for *pleasuring* is its uniform steady progress through the water. She glided through the sea and against the tide with scarcely any motion; and we consequently enjoyed a freedom from those jerks and that spasmodic action, if we may so apply the term, experienced on board a steamer propelled by paddles, by which the much-dreaded sea-sickness is materially promoted and produced. The facility and readiness, too, with which the vessel answered the helm, the ease and quickness with which she backed as well as advanced, and the narrow circle in which she pirouetted off Littlehampton, while the pilot was waiting for the flow of the tide, stamped her character as a first-rate sailer; while the promptitude with which she curved and twisted round the elbows of the circuitous stream up to Arundel bridge, with the most trifling action upon the closely adjacent banks, proclaimed the superiority of the screw over paddle wheels for canal navigation." The Committee of Management, in the name of the proprietors of the "Princess Royal," expressed their entire satisfaction in the application of the patent to their vessel, and stated, that in every thing connected with the machinery and its arrangements, her speed, and the facility with which she is managed, she far exceeded their expectations.

172. *Report of the Screw Propeller.*—The following extract is taken from a Report made, in 1839, by Captain Edward Chappell, R. N., who was deputed by the government to examine into and report upon the merits of Mr. Smith's screw propeller. The extract relates to the *increased power of steerage* obtained by this contrivance. "1. The additional force which a screw in the dead-wood gives to the ordinary power of the helm, is one of the most extraordinary facts attending this invention. The instant the screw begins to revolve, it throws a column of water astern, which impinges upon the rudder, and actually alters

the direction of the vessel's head a point or two before she gets any way through the water; as it is the stern, and not the head of the ship, which is most directly acted upon by the rudder, it may be that a hole in the dead-wood allowing the water to rush through the orifice, facilitates the turning of the stern by diminishing its resistance. 2. In running backward with the screw reversed, the same powerful effect is produced, by the current of water being drawn from the rudder in an opposite direction. 3. While steaming straight ahead in tolerably smooth water, the stream thrown astern by the action of the screw acts similarly to a rudder chock, keeping the helm steadily amidships, and propelling the vessel so direct, that I have often sent the steersman away, and she has steered herself six or seven miles without deviating a quarter of a point; and even in gales of wind, with a heavy sea on the bow, a spoke or two of the wheel either way is sufficient to govern her. 4. But it is in turning round that the astonishing effect of the screw upon the helm is most apparent. In the Frith of Forth this quality was thoroughly tested by Captain Boswall, R. N., and the other naval officers present. Putting the tiller hard over, the Archimedes was 2½ minutes performing the first circle, and 2¾ minutes making the second circle; although, as she loses her way by the rudder acting as a drag across her stern, it occupies longer time to make a second circle than the first, yet the space occupied is less in each successive circle, till the vessel revolves as it seems on a point, presenting, as I conceive, a manœuvre entirely new in the science of navigation." To these advantages, Captain Boswall adds the following, as attending the adoption of the screw propeller:—1. The necessity of an improved form of construction, by a finer entrance to the vessel, proportionate breadth of beam, and draught of water. 2. Less resistance to head winds and seas, and more valuable space within-board at no increased expense of materials, or cost per ton for building. 3. Constant action of the screw so long as the vessel has way through the water, or on her broadside, owing to the screw being unaffected by the trim, rolling, or pitching of the vessel, from its position in the after-body, or dead-wood. 4. Free use of the sails within six points of the wind on either tack, without ever causing the vessel to miss stays, or be in irons, in light baffling winds; and with the capacity of entirely disconnecting the screw in ten minutes, and re-shipping it in double that time, or of varying the motion so as to adapt the power of the engine to circumstances of weather.

PROPORTION OF POWER TO TONNAGE.

173. *Power and Speed of Steam Vessels.*—So long as the distances performed by steam vessels were comparatively short, the object of engineers and manufacturers of vessels was to ensure the greatest possible *speed*, and the attainment of this object was considered an ample compensation for considerable expenditure of fuel. But when steam communication was projected between remote parts, as between England and America, situated at a distance of 3000 miles from each other, the speed of the vessel, and the consumption of fuel, were no longer the exclusive objects of attention; for long voyages, the *supply of coal* presented difficulties, which could only be met by *apportioning the power of the engines to the tonnage of the vessel*, with the view of economizing fuel, though at a diminution of speed. The best proportion of power to tonnage in sea-going vessels has been a matter of much dispute; in the early steam boat engines, a small proportion of power was employed: the "Comet," of 25 tons burden, was furnished with engines of only three horse power, being at the rate of one horse power to eight tons burden. The great increase of power required to produce a certain increase of speed would appear to furnish a strong reason in favour of a low power and a small consumption of fuel; for it is found that the speed of a vessel, moving in still water, is as the square root of the

power; thus, if 20 horse power be required to propel a vessel five miles per hour, it will require 80 horse power to propel the same vessel ten miles an hour; or, in other words, a fourfold power to produce a twofold speed, a ninefold power to produce a threefold speed, and so on. But, in this calculation, no notice has been taken of the resistance offered to a vessel by winds, waves, and other opposing forces which occur in sea voyages—a resistance of such moment as to direct attention rather to the vessel's *capability for distance*, than to its speed. In order to determine the most economical ratio of the power to the tonnage in vessels destined for long voyages, many facts and experiments were brought together by Mr. Barlow; the results were, that in every instance, *the consumption of fuel was less, the smaller the power in proportion to the tonnage.* The following table, taken from that given by Mr. Barlow in the Appendix to Tredgold, represents the performance of Her Majesty's Admiralty Steamers to Corfú and Patras, and back, a distance of 5200 miles, made by eight different vessels, varying in tonnage and horse power. These voyages, having been made in every variety of weather, furnish a very valuable means for coming to a correct conclusion on the subject. The first three columns were taken from Parliamentary Reports, the others were derived from calculation. The fourth column represents the number of tons per horse power, obtained by dividing the measured tonnage (which includes the engine room) by the nominal horse power. The fifth column gives the actual consumption of coals during the voyage, calculated at the rate of 8 lbs. per horse power per hour, which is nearly the average for all engines. The last column is calculated by dividing the whole consumption by the tonnage, and represents the weight per ton consumed during the voyage, and consequently expresses the relative economy of each vessel. All the vessels, cited in the table, departed from Falmouth upon their respective voyages, during the three successive years 1832, 1833, and 1834.

Performance of Her Majesty's Admiralty Steam Packets, since the extension of their voyages to Corfú and Patras, together with their respective Tonnages and Powers.

Name of Vessel.	Measured Tonnage.	Nominal power of Engine.	Number of Tons per horse power.	Consumption of Coal, calculated at the Rate of 8lbs. per horse power per hour.	Bushels of Coal consumed during the Voyage, per Ton.
Firebrand . .	496	140	3·54	887,040	1788
Columbia . .	360	120	3·00	967,680	2688
Columbia . .	360	120	3·00	652,800	1813
African . . .	280	80	3·50	599,040	2140
Flamer . . .	496	120	4·13	732,670	1477
Hermes . .	730	140	5·21	1,128,960	1544
Messenger . .	730	200	3·65	1,612,800	2209
Alban . . .	294	100	2·94	1,094,400	3722
Firefly . . .	560	140	4·00	958,540	1711

174. *Remarks on the foregoing Table.*—Of the vessels mentioned in the table, the Columbia and the Flamer were furnished with Morgan's wheels, the others with the common radiating wheels; the economy of fuel arising from the use of the former wheel is hereby incidentally demonstrated. Mr. Barlow observes:—"1. In examining the table, it will be seen that vessels with similar wheels, whose tonnage is large in proportion to the horse power, in every case consume less fuel per ton during the voyage: for instance, in the 'Hermes,' which has the largest proportional tonnage, viz. 5·21, the consumption per ton is 1544 lbs.; being less than half that of the 'Alban,' viz. 3722, the tonnage of which is the least, viz. 2·94 per horse power. 2. In the vessels with Morgan's wheels, the largest proportional tonnage is the 'Flamer,' being 4·13 per horse power; the consumption per ton is 1477. In the 'Columbia,' the tonnage per horse power is 3·60, and the consumption per ton 1833. 3. The most direct comparison in the table is between the 'Hermes' and the 'Messenger,' being vessels of equal tonnage and similar wheels, but with different power,—the former being 140, and the latter 220 horse. The consumption of the 'Hermes' is not more than 2-3rds that of the 'Messenger.' We may, therefore, fairly conclude that the idea of a saving of fuel being effected by increasing the power of a vessel, is erroneous. Under particular circumstances it may happen that an additional power may effect a saving; but, generally speaking, it may be assumed, that a great economy of fuel will be obtained by diminishing the power of the vessel as much as possible, provided there is sufficient at command for the safety and management of the vessel, should circumstances require it." Alluding to the same table, with the view of showing the economy of fuel effected by the use of Morgan's wheel, Mr. Mornay observes:—"Of the 'Flamer' and 'Hermes,' the latter ought to consume the smallest quantity of coal per ton during the voyage, for two reasons: 1st, because she has much less power in proportion to her tonnage than the former; and

2dly, because, being a much larger vessel, even with the same ratio of power to tonnage, she ought to consume less fuel per ton by going faster; the reverse is, however, the case, as shown by the numbers in column 6. As another example, we may compare the 'Columbia' (Morgan's wheels) with the 'Messenger' (common wheels); here the difference ought to be more than in the foregoing example in favour of the common wheels, whereas it is still more in favour of Morgan's."—*Appendix to Tredgold.*

175. *Power and Tonnage for long Voyages.*—The following remarks are gathered from Mr. Barlow's excellent paper, already referred to. The larger the vessel, every thing being in proportion, the greater will be her capabilities both for speed and length of voyage. If, instead of increasing the power in proportion to the tonnage, it be only increased in proportion to the *resistance*, or the same speed is given to the vessel, then the power required will be not much more than half as much again; and, consequently, a voyage of more than one-and-half times greater length can be performed, while the spare room for cargo will be in the same ratio as the increase of the vessel, or as 1 to 2; and the vessel will have the same power to contend with adverse weather, as the smaller one with the larger proportion of power. These results have been fully confirmed by the performance of her Majesty's Mediterranean packets, and by experiments on the government steam vessels at Woolwich, in which the larger vessels generally give a greater speed, although the proportion of power is less than in the smaller ones; the consumption of coal per horse power is also less in the larger than in the smaller vessels. A practical advantage resulting from this principle is, that the diameter of the wheel increases in a greater proportion than the variation of immersion of the vessel, and is consequently proportionally less buried in the water when the vessel is laden, which is a cause of great loss of the power of the engine. "There is another advantage in a large engine, from its increased momentum, which causes

it to act as a fly wheel, and is, I am satisfied, of more importance than is generally supposed. One often hears of the motion of the vessel acting as a fly wheel to the engine; which is quite an erroneous idea, as the action of a fly wheel is that of a reservoir of power, receiving it at one time from the engine, and exerting it at another on the machinery to be put in motion. Now, as the paddle wheel is always exerting a force, although a variable one, on the water, it cannot possibly receive any assistance from the motion of the boat, which therefore cannot act as a fly wheel to it. It certainly so far assists it, as by its velocity through the water to allow the engine to make a greater number of strokes, and increases the momentum produced by its weight; but this is all it does, and this effect is greatly increased by giving more weight to the paddle wheels." The absolute or definite proportions of power and tonnage must be subjected to various modifications in reference to particular vessels; it may be stated, as a general rule, that the proportion of power to tonnage should not be greater than one horse power to two tons for short voyages; but, for the longer voyages, the proportion of power to tonnage should be about one horse power to from three to four tons, measured tonnage.

176. *Of Iron Steam Boats.*—The employment of *iron*, instead of wood, in the construction of steam vessels, has been found to be attended with many advantages: iron vessels are lighter, safer, more economical, more capacious, and more healthy, than those made of wood. 1. The *weight* of an iron vessel is less than one-half that of a wooden vessel; it therefore combines the advantages of a less draught of water, and a greater speed with equal power. 2. The greater *safety* of an iron vessel arises, first, from its mode of construction, the vessel being divided into water-tight compartments, and, secondly, from the nature of its material, which secures it from separation of its parts in stormy weather, and from fracture by collision with rocks; in the latter circumstance, the only injury likely to occur is that of

indentation. 3. The *economy* gained by the use of iron is an obvious result of its safety: there is no necessity for constant repair. 4. The greater *capaciousness* of an iron vessel is a natural consequence of its reduced weight and less draught of water with equal tonnage: its capacity for passengers and cargo may be proportionally increased; by making the iron vessel wider, a considerable amount of additional stowage room is obtained throughout its entire length. 5. The greater *healthiness* of an iron boat is occasioned by the nature of its material: in hot climates it is cooler than a wooden vessel, and it is perfectly free from vermin. The effect of the iron on the compass, which at first presented a difficulty, has been successfully counteracted under the management of Mr. Barlow; the indications of the compass may be afforded in iron vessels with the same precision as in those constructed of wood. The use of iron steam boats, hitherto employed only on rivers, is, in fact, likely to be soon extended to the most distant voyages by sea.

OF STEAM NAVIGATION IN AMERICA.

177. *Fulton's early Steam Boats.*—The peculiar geographical features of America—her extensive line of coast, her numerous islands, her magnificent rivers, her inland seas—were eminently favourable to the enterprise of steam navigation. The early experiments of Fulton on the Hudson, have been briefly noticed at the commencement of this chapter. In his first steam boat, some alterations were introduced into the machinery of the engines: the cold water cistern of Watt's engine was abandoned, and, instead of this, an increased capacity was given to the condenser; in Watt's engine, the condenser was half the diameter and half the height of the cylinder, and consequently one-eighth of its capacity; in Fulton's engine, the condenser was of the same diameter and of half the height of the cylinder, and

was therefore one-half of its capacity; the injection water was supplied by a pipe inserted into the bottom of the condenser. There were two working beams to the cylinder, but the form of the beam varied from that commonly in use, being constructed like the inverted letter L, in order that the motion might be communicated to the crank, either from the horizontal part of the beam, according to the practice now commonly adopted, or from the vertical part, after the manner of a bell-crank; the latter plan was found the more convenient, and the connecting-rod was accordingly extended horizontally between the vertical arm of the beam and the crank. The axles of the cranks were provided with spur wheels, and pinions, and the velocity of the engine was regulated by a heavy fly wheel, placed on the axles of the pinions. The speed attained by early experiments of Fulton's first steam boat was only four miles an hour; this rate of speed was afterwards increased to six miles an hour; and in vessels of a later construction, he was enabled to attain a speed of nine miles an hour, with which he appears to have been satisfied. The *form* of Fulton's boats was unfavourable to speed: they were flat-bottomed, with full round bows and sterns, and therefore drove the water under the vessel, instead of cleaving it and pushing it aside.

178. *Stevens' Steam Boats.*—The application of steam to sea voyages was first successfully undertaken by the elder Stevens of Hoboken; his earliest steam boat was sent by sea to navigate the Delaware. The engine of Stevens differed less from the plan of Watt than that above described. He employed the enlarged condenser of Fulton, but retained the working beam as used by Watt. Considerable improvements were now introduced by Robert L. Stevens, the son of the elder person of that name; a steam boat, constructed by him, performed the passage from New York to Albany, a distance of 145 miles, in twelve hours, thus exceeding the greatest speed of Fulton's boats by two hours. Stevens contributed much to the improvement of the *form*

of the American steam boat; he constructed his boats of greater length, abolished the round bows and sterns, and gave them a fine entrance, so as to enable them to rise over the water, instead of driving it before them. The result of his improvement was presently seen in an increase of speed from nine to thirteen miles an hour. Another change of great importance consisted in the employment of a very long stroke, of a lengthened crank, and in the application of the *expansive* force of steam; the cylinder was lengthened, and the steam cut off at half the stroke. The practical advantage of employing steam expansively was first discovered in America by Adam Hall, director of the West Point Foundry, who proved that the power of a given engine might be doubled by loading the safety valve with 57 lbs. per square inch, and cutting off the steam when one-eighth of the cylinder had been filled, and that a saving of two-fifths of the fuel was effected at the same time. Stevens at an early period adopted the method of dry condensation, which had been previously attempted by Watt and others, but he was obliged to abandon it, and return to the mode of condensation by injection. The first successful experiment of dry condensation was made by Mr. S. Hall, of this country, as has been already explained.

179. *Speed of American Steam Vessels.*—The unparalleled speed recorded of the American steam vessels, has been the subject of astonishment, and even of doubt. The boats of Stevens realized a speed of thirteen miles an hour, while the speed of sea-going vessels in Europe is at the average of ten miles an hour. Dr. Renwick made, in the "New Philadelphia," one of the most remarkable passages ever performed. "Leaving New York at five o'clock, p.m., with the first of the flood, he landed at Catskell, distant 111 miles, at a quarter of an hour before midnight. As passengers were landed and taken in at seven intermediate points, the rate at which the passage was performed was *not less than eighteen English miles per hour*. Now as the current in no case exceeds four miles per hour, the absolute velocity

through the water must have been fourteen miles."* These high rates of speed appear not to be attributable to any increased force of the engines, or to any definite relation between the power of the engines and the tonnage of the vessels, and certainly not to any superiority of workmanship in the construction of the machinery, this being confessedly on the side of the European vessels. But there are other circumstances to be taken into account, in explaining the extraordinary rates of speed attained by American steam boats. 1. *The waters which are navigated* by most of the American boats are very different from those for which European vessels are constructed. The former consist of rivers with smooth surfaces, sheltered bays, or arms of the sea, exposed neither to waves nor to wind; the latter are the open seas, exposed to the influences of wind and wave. Hence, in the construction of the American vessels, a light slender form is the great object required; it is not uncommon to see vessels of 200 feet in length built entirely of thin planks, yet of sufficient strength to bear the weight and action of engines of 600 horse power. 2. *The position and form of the machinery* in American vessels are also conducive to their speed. In European vessels, the machinery is placed beneath the deck; hence, the stroke of the piston and the length of the crank are reduced below the proportion originally assigned to them by Watt. In America, the machinery and the cabins are raised above the deck of the vessels; this position admits of the use of more powerful engines, or, in lieu of these, of a much greater length of stroke and of crank: it was by means of the latter expedients that the speed of the "New Philadelphia" was made to exceed that of vessels propelled by more powerful engines than her own. 3. A third source of speed in the American vessels is found in the employment of the *expansive force of steam.* The effect of this method is an increased velocity of the piston, which, instead of moving, as in our manufacturing engines, at the rate of about 250 feet per second, is enabled, by this mode of working the steam, to double that rate of speed. Dr. Renwick states that the velocity of the piston in the "North America" was carried up to 384 feet, in the "Fulton" to 450 feet, and in the "Cornelius Vanderbitt" and "Highlander," to 600 feet, per second. In these cases, the length of the cylinder, and the diameter of the wheels, are often considerably increased; in one instance, the diameter of the water wheels has been increased to thirty feet, and the stroke of the piston to twelve feet. Additional velocity is obtained by the use of large valves and steam passages; the flow of steam from the boiler is thus rendered more rapid, and the velocity of the piston proportionably increased. 4. *The form of the paddle wheel* employed in America contributes to the speed of the vessels. Dr. Renwick describes this form, by supposing a common paddle wheel to be cut into three parts, by planes perpendicular to its axis; one of these is supposed to remain at rest, the second is moved through one-third, and the third part through two-thirds, of the space intervening between two contiguous paddles. This form of wheel was introduced by the younger Stevens, and is now universally adopted.

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* *On the Steam Boats of America*, Appendix to Tredgold. Dr. Renwick states that the *absolute velocity* of a vessel propelled by steam in a current does not differ when the direction of the motion is *with*, and when it is *against*, the stream. "Let us suppose," he says, "that a steam boat is abandoned to the current: in this case it must speedily acquire the velocity of the stream, and be at rest in relation to the water on which it floats. When the machinery begins to act, no difference of circumstances can arise from the direction in which the prow of the boat is turned, and all the motions in reference to the mass of fluid will be performed exactly as if that mass were not in motion. In moving with the current, then, the rate of progress by the land will be the sum of the ordinary rate of the boat's motion, and the velocity of the stream; in moving against the current, the rate of progress will be the difference between these two velocities."

180. *Different Classes of American Steam Boats.*—Mr. Stevenson observes, in his work on *Engineering in America,* that, "with the exception of the vessels navigating the lakes, and one or two of those which ply on the eastern coast, there is not a steamer in the country which has either

masts or sails, or is commanded by a professional seaman." There are three classes of boats used in America:—the *Eastern Water Boats*, characterized by small draught of water, great speed, and the use of condensing engines of large dimensions, having a great length of stroke; the *Western Water Boats*, with greater draught, less speed, and high pressure engines of small size, worked by steam of great elasticity; and the *Lake Boats*, of a stronger construction, furnished with sails and rigging, and propelled by powerful engines, like sea-going vessels.

(1.) *The steam boats of the Hudson* exceed all others in speed, and are unrivalled in river navigation. They vary from 180 to 240 feet in length, and from 20 to 30 feet in width. The table on the following page, taken from the paper of Dr. Renwick, gives the particulars of several steam vessels belonging to the port of New York. The velocity of the piston, and the high pressure of the steam employed, are remarkable in these vessels. All the vessels, given in the table, are furnished with one engine only, except the Massachusetts and the Erie, which have two engines each.

(2.) *The steam boats of the Mississippi* are of a heavier structure than those of the Hudson; they vary from 100 to 700 tons burden, and draw from six to eight feet of water. These vessels are propelled by non-condensing engines, worked by steam of very high pressure, varying from 100 to 150 (!) lbs. on the square inch. Mr. Stevenson describes the effect of this practice in the case of the "Ontario," in the following emphatic words: "The steam had been got up to an enormous pressure, to enable her to get off, and the volume of steam discharged from the escapement pipe at every half stroke of the piston, made a sharp sound almost like the discharge of fire-arms, while every timber in the vessel seemed to tremble, and the whole structure actually groaned under the shocks." Mr. Stevenson considers, that the explosions, so frequent in America, are sometimes caused by the use of steam of this unusually high tension; and frequently by a deficient supply of water, *Particulars of several Steam Vessels belonging to the Port of New York.*

Names of Vessels.	Length of Deck.	Breadth of Beam.	Draught of Water.	Diam. of Wheel.	Length of Paddles.	Depth of Paddles.	Number of Engines.	Diam. of Cylinder.	Stroke.	Number of Revolut.
Massachusetts . .	200 ft.	29·5 ft.	8½ ft.	22 ft.	10 ft.	28 in.	2	44 in.	8 ft.	26
Swallow	232·8	22·5	3¾	24·2	11	30	1	46	—	27
Rochester	200	25	3¾	23·5	10	24	1	43	10	28
Utica	200	21	3½	22	9½	24	1	39	10	—
Erie	180	27	5½	22	15	34	2	44	10	27½
Belle	190	26	4½	24·5	11	26	1	50	10	25
New York . . .	230	22	4	24	11	30	1	50	10	—
Dewitt Clinton . .	230	28	5·5	21	13·7	36	1	65	10	29
Arrow	160	21	4·3	22	8	22	1	31	11	27
Neptune	220·7	25	7·5	25	9·4	36	1	50	11·5	—
Home	212	22	6·5	25	10	24	1	56	9	25

causing the boiler to become red hot; in this case, the water, when supplied, evaporates more rapidly than it can escape by the safety valve. In the Mississippi steamers, the paddle wheel shaft is so constructed, that the projecting portions of it on each side of the vessel can be thrown out of gear at pleasure, so that the shaft may revolve without producing any revolution of the wheels; by this means, when the vessel is stopped, the engines continue to work, and are employed in pumping water into the boiler.

(3.) The *sea-going steamers* of America are constructed on a principle which appears, to Europeans, insecure: there is a *weakness* in them, owing to the great proportion which their length bears to their breadth and depth. Dr. Renwick states, that "their length is as much as eight times their breadth of beam, and the form of their prows and sterns extremely acute: hence, the tendency to *hog*, and break their backs, is great; and one instance has already occurred, where a new vessel has gone to pieces by mere stress of weather. Vessels of this model are exposed to being washed from stem to stern by the waves." Another practice, adopted in sea-going vessels in America, is characterized by Dr. Renwick as a prominent mistake. "Departing from the practice which had become sanctioned by successful usage, of employing two engines placed upon the wheel guards, a *single one* has been substituted. This being necessarily placed in the plane of the keel, the rolling of the vessel is rendered more rapid, and more likely to be injurious. It is, indeed, a well-known principle in the stowage of vessels, that the rolling is to be rendered less violent by placing the weights at the greatest possible distance from the plane of the keel, as well as at the greatest height which is consistent with stability. The use of a single vertical engine of long stroke is attended with another difficulty, viz. that it requires a large opening to be left in the deck of the vessel, which cannot be sufficiently defended from the influx of the sea; for the bulk-heads which surround it, cannot be rendered strong enough to resist a violent wave." The first steam boat which crossed the Atlantic, was the "Savannah," a boat built and equipped at the port of New York. This vessel proceeded, in 1819, from New York to Liverpool, without stopping at any intermediate port; she then went to St. Petersburgh, touching at Copenhagen; she then recrossed the Atlantic. It appears that steam was employed only during part of the voyage. Each trip was made in twenty-five days. The enterprise, thus undertaken by America, was successfully completed by the exertions of our own countrymen. In 1838, the "Sirius" performed the passage from Cork to New York in nineteen, and returned in eighteen, days. The "Great Western" left Bristol a few days after the Sirius, and reached New York in fifteen days, where the Sirius had arrived only a few hours before; she returned home in fourteen days. The average speed of this vessel was nine nautical miles per hour.

RECAPITULATION.

139. Who were the earliest projectors of steam navigation? By whom was the invention first practically applied? —140. In what respect does the mode of propulsion of a steam vessel agree with, and in what does it differ from, that of a land engine? What kind of engine is commonly used in steam vessels? What is the relative position of the beam and cylinders in land and marine engines, respectively? What is the proportion of the cylinders in each kind of engine?—141. Explain the general construction of a marine boiler. What object is secured by this mode of construction?—142. How is the thermometer employed as an indicator of the saltness of the water in boilers? What was the result of Mr. Dinnen's experiment on this subject? What is the principle of Dr. Lardner's contrivance for indicating

the saltness of the water in boilers? Explain the method adopted by the Messrs. Seaward for this purpose.—143. What is meant by *blowing out?* At what intervals is this process usually repeated? What is the object of brine pumps? How is the heat of the discharged brine economized?—144. How is the *power* of a marine engine estimated? What is the objection to this mode of estimation? What are the comparative advantages of a long, and of a short, stroke of the piston? What is the estimated velocity of the piston?—145. Explain the apparatus connected with the cylinder; the position of the beam; the action of the beam on the connecting-rod and crank; and the method by which both the beams of each engine act in propelling the vessel.—146. What mode of condensation has been generally adopted in the engines of steam vessels? What is the usual size of the condenser, relatively to the cylinder? How is the vacuum in the condenser ascertained? What are the usual proportions of the air-pump in marine engines? —147. What is the method of condensation adopted by Mr. Samuel Hall? What are the objects of his invention, as set forth in his patent?—148. Explain the construction of Hall's patent condenser.—149. Describe his distilling apparatus.—150. What is the plan of the steam saver?—151—153. State the advantages which the patent engine of Mr. Hall possesses over the common injection engine.—158. What is the novelty in Mr. Howard's method of vaporization? What advantages are proposed by it? Explain his method of generating steam; and his process of condensation. What was the result of his experiment in the "Comet"?—159. What are the usual dimensions of the valves and steam passages? Explain the position of the eccentric. Describe the apparatus of the expansive valves. —160. By what modifications of the engine may the *expansive* principle of steam be brought into more extensive operation?—161. Explain the causes which produce a loss of power in the construction of the paddle wheel.—162. What is the construction of Field's cycloidal wheel? What are the advantages, and disadvantages, of this contrivance?—164. Describe the general construction of Morgan's paddle wheel. What are the comparative merits of the paddle wheels already described?—165. How is the power of an engine affected by deep immersion of the paddles?—166. What is meant by a *reefing* paddle? What are the advantages obtained by Mr. Hall's patent reefing paddle wheel?—167. To what circumstances is the success of the "Ruby" steam packet attributable?—168. Enumerate the several parts of the marine engine, with reference to the plate of the frontispiece.—169. Describe the construction of the engines of the "Gorgon."—170. Explain the construction of the screw propeller.—172. What are the advantages of this mode of propulsion?—173. In what ratio does the *speed* of a vessel increase with increase of power?—174. What are the results of the experiments detailed by Mr. Barlow? What evidence do these experiments furnish of the relative economy of using Morgan's wheel and the common radiating wheel?—175. What are the further advantages arising from the principle on which these experiments were founded?—176. What are the advantages gained by the substitution of *iron* for wood, in the construction of steam vessels?—177. In what respects did the engine of Fulton's first steam boat differ from that used in the present day? What rate of speed was attained by Fulton's boats? What was the form of his boats?—178. What improvements were introduced by Stevens?—What rate of speed was attained by his boats?—179. On what circumstances does the great speed of the American steam vessels depend?—180. How are the American steam boats classified? What are the peculiarities of the steam boats of the Hudson, and of those of the Mississippi? What are the defects of the sea-going vessels of America?

APPENDIX.

1. ON THE CAUSES AND PREVENTION OF SLIPS OR FALLS OF EARTH FROM THE SLOPES OF EXCAVATIONS ON RAILROADS.

181. *Slip on the Great Western Railway.*—The recent calamitous accidents which have occurred on the Great Western and the Croydon Railways, owing to falls of earth from the slopes of the cuttings, have excited considerable interest on the subject. The shock felt by the public, on the former of these occasions, was testified by the circumstance, that the passenger traffic on the Great Western line for the week following the catastrophe, was upwards of £2000 less than that for the week immediately preceding it. On the 24th of December last, a train, consisting of 17 goods waggons, a station truck, and two passenger trucks containing about 38 persons, on reaching the middle of the Sonning-hill cutting, about two miles and a half from Reading, came in contact with a mass of earth which had fallen from the slope on the side, and covered one of the rails to the depth of about four feet. The engine ran off the rails, dragging the tender with it; the passenger trucks were thrown athwart the line; the passengers were dashed out by the concussion, eight were killed upon the spot, and seventeen more or less severely wounded. The soil where the slip occurred, and immediately opposite, where there has been another slip, is *clay;* but, except at these points, the surface of the slope was covered with grass sward. The

cutting is within one or two feet of 60 feet perpendicular altitude, and the slope is two base to one perpendicular, or, as it is technically called, *two to one*. The length of the slip was about 90 feet, but the quantity of earth which fell was comparatively small. Upon the top of the slope was a spoil bank, from 150 to perhaps 250 feet wide, and averaging 12 or 14 feet deep. Mr. Herapath states, that the slope is flatter than that of other cuttings which he has known to stand well, though apparently of as bad or worse material.

182. *Slip on the Croydon Railway.*—On the 7th of January last, an extensive fall of earth took place between New Cross station and Finch's Bridge, on the Croydon Railway, by means of which the surface of the east line was covered for about fifty yards, to the depth of nine feet. "The soil composing the slip is of the most treacherous and heterogeneous description. The foundation of the cutting is of blue clay, lying upon a stratum of gravel, shells, sand, &c., and the earth composing the slip is of a yellow sort of clay of a most soaping nature. The soil which has fallen contains patches of blue clay, sand, ochre, sulphate of lime, septaria or cement stone, and other materials of a highly pervious description, so that when the earth becomes saturated with water, it appears to be almost in a state of fermentation from the different masses being disintegrated and moving one over another. This slip is no doubt caused by the pressure on the slope, which, towards the north part of the cutting, has also forced up the bed of the cutting, together with the rails. A ditch or drain was observed on the top of the cutting, parallel to it, which, it is to be feared, has helped to cause this slip, if, indeed, it has not been the primary cause of it."—*Railway Magazine*, January 8, 1842.

183. *Effects of Water on Clay Cuttings.*—"It is of no use," observes a writer on this subject, "to look for a remedy in any new arrangements of the rails, or in the adaptation of the engine. *Do what you will*, in these respects, a *momentum*, produced by a weight of 12 or 14 tons, running with a velocity of 20, or even 15 miles an

hour, suddenly checked, would bid defiance to it. The surest and the best remedy is to prevent *obstructions*." Hence, the question becomes one of *geological* importance, and involves an acquaintance with the properties of clays, sands, and limestones, the varieties of which constitute the great mass of strata composing the crust of the earth. The following remarks are condensed from a paper recently published in the "Surveyor, Engineer, and Architect," with particular reference to the railway accidents above described. The writer observes that *clay* is a material which presents to the engineer more uncertainty and difficulty, and therefore requires more of his judgment and experience, than all other kinds of cuttings together; that almost all geological formations comprise strata of clay, which the engineer may have occasion to penetrate in carrying on the works of railways; and that no dependence whatever is to be placed either upon the apparently firm or really tenacious character of the clays, which enables them for a short time to stand quite perpendicular, but which is soon found to have been so completely deceptive, that slip follows slip in rapid succession, till the whole face of the cutting is broken up. The clay cuttings are subject to two kinds of destruction—the effect of water on the face of the slope, and the effect of water penetrating from behind. On these *two causes* of falls of earth from the slopes of cuttings, this writer observes:—

(1.) "*When their section is left exposed on the face of the slope*, they readily imbibe all the moisture which falls upon them in the form of rain and snow, and the process of destruction thereupon immediately commences something in the following manner. The rains wash out of the crevices and hollows of the stratification numerous particles, which the water will either dissolve or hold in suspension, and then the natural hollows and porosity are somewhat increased. Dry weather or winds probably succeed the rains, and many loosened particles are converted into dust and borne away. Slight diminutive falls now take place on the slope, but these are at first so small as to be scarcely perceptible; they are, in fact, the roofs of the minute caverns which have been already formed; by the succession of atmospheric changes these caverns are greatly enlarged, and the whole action is much extended, until at length a considerable part of the slope is undermined, and a serious fall takes place, simply because the support of a heavy mass has at last been entirely carried away. All this, we are to observe, has been effected without water from behind; and as this mode of action, where it either exists or is apprehended, should give rise to an entirely different treatment by the engineer in dressing the slopes, it is important to distinguish between the two kinds of destruction.

(2.) "*Where water penetrates from behind*, it soaks into the surface through some porous or permeable stratum which admits of its percolation, and although solid clay, even without puddling, is a tolerably water-tight material, yet most of these shales are so loosely laminated, or contain so much sand in the partings or seams of the laminæ, that water will find its way between them without much interruption. When the water has once arrived at the slope, the supply of moisture from behind being tolerably constant, its *modus operandi* is not difficult to trace. Minute particles, as before, are at first washed out. Warm weather dries the sides of the pores into dust; winds, rain, and hail storms carry out the dust, and even larger particles; larger hollows in time are formed, the tendency of every natural phenomenon being to increase and not to retard the destroying process, till at last serious falls begin to take place, and then people begin to exclaim, for the first time perhaps, that the slope was not sufficiently flat." The writer of these observations ridicules the outcry which is generally made by the public against the steepness of the cuttings; he repeats that a slope of *two to one* is amply sufficient, and points out the case of Highgate Hill, where the slopes at this very hour are six or seven to one, and where they are even now slipping.

184. *Effects of Frost on Cuttings.*—The injurious effect of *frost* on cuttings is frequently masked by the dry appearance of the frozen surface of the slope; this circumstance appears to have deceived the inspectors of the slopes of the Sonning-hill cutting; *they thought the wet was dried out of it by the frost;* but the mischief was at that very time at work beneath the surface, and, as soon as the frost broke up, or even relaxed in its severity, the slip immediately took place. "The Sonning cutting consists of nearly horizontal strata of sand and clay alternating with each other, and through the permeable beds percolates a certain quantity of water, which is received into them somewhere on the surface of the ground, at a greater or less distance from the top of the slope, and of course in a greater quantity than usual after heavy rains. When this water reaches the slope, if nothing prevents its escape, the consequences take place which we have described above; but if any thing obstructs the trickling out of the water, the particles acted on by the water, and carried by it either in solution or in mechanical suspension, are accumulated beneath the frozen face of the slope, where the closeness and solidity of the stuff are increased by the infusion of the particles transported by the water. This pressure continues until either the frost gives way, or until the pressure itself becomes sufficient to break through the frozen surface, when a hollow is immediately formed, and a portion of the previously incumbent earth, being left without support, immediately falls. Whether the slip thus occasioned be considerable or not, depends upon the extent of the hollow suddenly formed by the breaking out of the interior stuff; but in either case, we hold it to be an error that slips so occasioned take place without warning. We consider the strata themselves, by their very disposition and structure, afford a warning; the frost accumulates the evidences of danger, and, in most cases, previous swelling on the surface of the slope clearly points out the coming danger in a voice of warning which cannot be mistaken." The writer of these remarks does not attach

much importance to the *expansive* effect of frozen water in producing slips of cuttings. He observes, that where natural fissures or considerable natural cavities exist, the water which fills them may, by being frozen, burst the surrounding materials; but that, in the case of ordinary cuttings, the severest frost does not penetrate more than eight or ten inches into the ground, so that the water below this level is beyond its influence, and not subject to the expansion which would be occasioned by its congelation. It may be also remarked, that slips seldom take place during the frost, as would be the case if they were produced by the freezing of water, but immediately after the frost, as might naturally be expected from the cause above explained.

185. *Treatment of the Surface of Slopes.*—There are two ways of treating the finished surfaces of slopes, according as the cuttings are originally wet, or free from moisture. These are, *first*, to cover the surfaces of deep cuttings with a soil of vegetable mould, which is usually sown with rye grass and clover seeds, in order to protect the surface of the slope from external influences; or, *secondly*, to face them with greensward turfs. On this point, the above writer observes:—"Where the strata intersected by the cutting are found perfectly dry, and where there is no reason to apprehend the penetration of water from behind at any future time, we are strong advocates for the practice of protecting the slopes either by soiling or turfing, because this expedient will prevent the only injury to be apprehended in such a case, namely, that which might arise from external causes acting on the face of the slope. But, on the other hand, when the strata contain water, or even when it is at all likely, from the alteration of watercourses, or from any changes which may take place on the surface of the adjacent lands, that during heavy rains, or at any other time, water may penetrate from behind, and reach the surface of the slope, then, in all such cases, a more dangerous or injudicious expedient than turfing cannot possibly be adopted, and the following is our reason for thinking so.

Referring to what has before been said on the action of water penetrating behind the slope, and carrying out minute particles as the first part of the destructive process, it is obvious that this must for a time be impeded where the surface of the slope is covered with turf. Thus an effect analogous to that of frost is produced by any artificial covering of the slope; an accumulation takes place behind this covering, and exerts a pressure which in time bursts suddenly through it, and then down comes a considerable fall. Hence this very important objection to artificially covering the slopes, that the incipient action of water from behind is concealed from observation, and is probably only observed just before the slip is about to take place. It is true that a heaving of the surface where it is turfed is usually produced before the confined stuff breaks out, and this, if closely observed, ought to afford sufficient indication of the coming danger; but this appearance, as in those cases where the ground is disturbed during frost, may frequently, and no doubt is frequently, overlooked, and disastrous consequences ensue from the negligence.

186. *Illustration of the above Principles.*—"The New Cross cutting on the Croydon Railway had its slopes on both sides turfed, and presented, when finished, a very handsome appearance: at this time, also, there was no appearance of water, the cutting, when finished, being remarkably dry. It happened, however, that more than twelve months after the completion of the cutting, a bed of sand, which had hitherto been dry, was penetrated by water, which shortly converted it into a running or quicksand, and eventually brought down lately some very extensive slips. It can scarcely be said that any error of judgment was displayed in covering the slopes of this cutting, for probably there never was a work which reflected more credit on the engineer than this cutting, and probably every engineer of the day would have considered the slopes safe, and, calculating on their remaining dry, would have followed Mr. Gibbs' example of covering them; yet, having added some-

what to our stock of experience, let us here derive a lesson which may prove useful in future, and determine to investigate well the possibility of the slopes ever being subjected to the power of water from behind, before we adopt the practice of soiling or turfing them. Had the slopes of the New Cross cutting not been turfed, it is probable that the interior disarrangement would have been observed on the surface of the slope, and proper precautions taken to prevent the slip, or at any rate to prevent mischief happening from its fall. In all cases where existing slopes are artificially covered, and particularly where the surface is much concealed by vegetable growth, we would recommend the most watchful attention, in order that the slightest heaving or swelling of the slope may be observed and acted upon. The practice of soiling the slopes with a few inches of vegetable mould, does not appear so objectionable as that of turfing, because a very slight pressure will break through the loose soil or mould, and the danger will be at once perceived."

187. *Prevention of Slips by means of Puddle-dams.*—It has been usual to secure the slope by driving piles, or picketing it with faggots, and then, after it has been left open for some time to drain, it is usually cut back at a flatter inelination than at first. This proceeding is characterized by the writer as quite inefficient as a permanent remedy, and the following class of expedients is suggested by him for the prevention of slips in cuttings, where they have not hitherto occurred. The first point is to ascertain the constituent qualities of the separate strata intersected by the cutting, with reference to their admission of, or resistance to, the penetration of water; and this will depend on their more or less arenaceous character. Wherever beds of sand or gravel occur, however thin they may be, danger from undermining is always to be apprehended. The dip of these beds across the railway should therefore be ascertained; this may usually be done, when the stratification is regular, by identifying them with the corresponding beds on the other side of the cutting, and some clue will thus be afforded as to

the line at which these beds crop out on the surface above. It is true that the indication thus afforded is often very deceptive, because a change may have taken place in the inclination of the strata, which cannot be observed, and thus all attempts to discover the precise outcrop may become utterly fruitless. Supposing, however, the dip to be uniform, and the outcrop discovered, it is at this very point where the principal danger will arise; and the great object, therefore, is to prevent the penetration of water at this point. For this purpose two expedients present themselves, viz. the construction of a *puddle dam* either at the outcrop of the stratum, or at the point where the stratum appears on the slope. The former locality is to be preferred, whenever it is practicable to find the outcrop, for by this means the water is prevented from sinking at all into the stratum. The *puddle* employed on these occasions consists of clay, mixed with a proportion of sand; these, being well worked together, form an effectual *dam* to the water, which will flow over the surface to some more permeable stratum. The size of the puddle dam will depend upon the length and dip of the bed of sand; for cutting off the water from a bed of two feet in thickness, a dam of about 2 yards × 1½ yard, or 3 cube yards of puddle per yard lineal, will commonly be sufficient. The puddle should be extended longitudinally as far as the dangerous stratum makes its appearance on the slope; and where it is at once effected as a part of the original work, its cost will be quite inconsiderable, being not more than three shillings per lineal yard. In cases in which the precise line of outcrop cannot be ascertained, it is recommended to trench and puddle a certain extent of surface, perhaps a zone of 50 yards or more; the cost of this, being a mere surface work, need not be more than a foot in depth, and will not exceed, in point of expense, about fourpence per square yard.

188. *Prevention of Slips by protection of the Slopes.*—In many clay cuttings, the permeable strata cannot be traced to the surface, or outcrop, as when the strata of sand and

clay are so intermixed as to have no regular dip. In these cases, the treatment must be applied to the *slope* itself; and "it consists in a protecting work of rough unhewn stones, about six feet in thickness, the stones to be pitched at right angles to the face of the slope. Almost any description of stone will answer for this purpose; and, if rough blocks of sandstone or limestone, such as are used for building, cannot be procured, blocks of hard chalk may be placed in the work. It is evident that such a protection will cost very little in any district where stone is abundant. Even in the neighbourhood of London, where it would be cheapest to construct it of chalk, the cost of a protecting work of this kind would not exceed 40s. per lineal yard. It should be understood that, in placing these stones, no mortar is to be used, and any vacuities which may exist where they are placed together, will not deteriorate from the efficiency of the work, because the puddle which is to be carried up behind the wall, will effectually prevent any water from reaching it." The paper, from which these extracts are made, concludes with a sketch of a design for preventing future slips at New Cross Hill. The writer maintains that all future slipping *may* and *can* be prevented, if proper means be taken to protect the slopes.

II. OF EXPLOSION OF STEAM BOILERS.

189. *Explosion of Steam Boilers.*—In 1839, an essay was read by Mr. Hugo Reid, before the Philosophical Society of Glasgow, on the causes and means of preventing the explosion of steam boilers. These casualties, it appears, had become more frequent. From 1817 to 1836 inclusive, a period of twenty years, there were 14 explosions of steam vessel boilers, occasioning the loss of thirty-three lives; and during the period of the following two years, and a part of the third, no fewer than 10 explosions had occurred, by which forty-five lives were lost. During the year 1838,

three vessels were destroyed, probably from defective machinery, and one hundred and fourteen lives sacrificed. Mr. Reid, writing in the year 1839, states, that the explosions since the commencement of 1837, have been *five times* that of the average of a similar period in the preceding twenty years; whereas the number of steam vessels since 1837, is *less than three times* that of the average of three years, from 1817 to 1836 inclusive. The three years 1837-9, being not yet complete, renders the increase in explosions still larger in proportion. This proportion—of explosions to the number of steam vessels—may be said to have been, since 1837, nearly double what it was previously. These accounts are startling,—and the more so, when we are informed, that a few simple contrivances would render explosions impossible, and that it is disgraceful that such an occurrence as the explosion of a steam boiler should ever take place. Explosions of steam boilers are distinguished by Mr. Reid into two kinds — "*explosion outwards*, or *explosion* properly so called, when, from the elastic force of gaseous matter within the boiler being greater than it can support, it is burst, and its sides forced outwards; and *collapse*, when the sides of the boiler are forced inwards by the atmospheric pressure, from want of support, arising from diminution of the resistance within. When the flues pass through the boiler, *explosion* of the latter is at the same time *collapse* of the flue, which must be distinguished from the true collapse first mentioned. It is a collapse as regards the flue, an explosion as regards the boiler." Explosion, properly so termed, may arise from inefficiency of the safety valve, or from weakness of the boiler.

190. *Explosion from Inefficiency of the Safety Valve.*— 1. The safety valve is sometimes *overloaded* by the engineman, or kept closed by pressure on the lever connected with it. There is a temptation to resort to this practice in cases of competition among steam vessels plying on the same line, or when a railway engine has to ascend an inclined plane, or when it is desired to accumulate steam of high pressure for

the purpose of a good start. Mr. David Napier stated, in his evidence before the jury at the inquest on the explosion of the Victoria, that "the engineer ought to have removed the extra weight on the lever at Blackwall, going and coming, and the accident could not have happened." Every boiler should be provided with two sufficient safety valves, *one of which should be inaccessible to the engine-man*, and the other accessible both to him and to the persons on board the packet. In cases in which there is only one safety valve, the weights should be so adapted as to be capable of being removed *all at once* by means of a lever, and not *singly*, as is the case in some of the smaller boats. Mr. Reid properly observes, that "no one can foresee those sudden emergencies at which the action of the safety valve is essential to give vent to an accumulation of steam; and that it cannot be looked upon as security *at all*, unless it be *always* in such a state as to rise instantaneously whenever the steam tends to acquire undue force." 2. The aperture of the valve may be of *insufficient size*. On this subject, Messrs. Maudsley and Field observe:—"The safety valves should be large enough to admit of the escape of the whole of the steam, when the engine is suddenly stopped, without its rising more than half a pound on the inch beyond the usual pressure. Two valves, having an area of one square inch for every horse power, are sufficient for this purpose. Those valves should be so constructed that no increase of weight can possibly be put on, even by the engineer; and there should be provided an apparatus by which they may be conveniently lifted from the engine-room, when it is requisite to ease off the steam."—*Report of Messrs. Parkes and Pringle.*

191. *Explosion from Weakness of the Boiler.*—In the "Report" above alluded to, the following statement was made by the Messrs. Seaward:—"Of the various causes which have been suggested by different persons to account for the explosions of steam boat boilers, such as the sticking of the safety valves, the igniting of explosive gases, the loss

of feed and heating of the metal plates, the sudden immission of a large quantity of feed and consequent generating of an unusual volume of steam, and other pretended causes of similar character, not one, in our opinion, is deserving the smallest attention; they should be all scouted as merely calculated to mislead the inquirer from the only true cause of these accidents, which is simply, that *the materials of the boiler are not sufficiently strong to withstand the force of the steam.* It is, however, true, that a boiler may lose its water so far as to allow some of the internal parts to become red hot, and thereby assist in producing a collapse when high-pressure steam, or steam of a dangerous pressure, is used; but the circumstance of some internal part of a boiler becoming red hot, ought not to be considered as the true immediate cause of the accident, because the losing of feed in a boiler, and the consequent heating of a flue red hot, is a mishap of very frequent occurrence in low-pressure boilers; but no accident has ever occurred on such occasions, calculated to occasion loss of life or personal injury. The fact is, that the parts of a boiler liable to become red hot, should even in that state be sufficiently strong to resist the force of the steam, so that no dangerous collapse shall take place; and all good low-pressure boilers are so made." The Messrs. Seaward state their belief, that of the many accidents occurring in steam vessels through imperfection of the boilers, it will invariably be found, that they have happened in vessels in which steam of high pressure has been used, and in no instance with steam of low pressure, that is, of a pressure not exceeding 5lbs. on the square inch. They further state, that of the numerous accidents occurring to steam boat boilers from the use of high-pressure steam, or steam of dangerous pressure, it will be found, that a large proportion, probably half, have occurred through the collapsing of large internal cylindrical chambers or flues employed in such boilers; the remaining accidents being occasioned through the bursting or rending of the external casings of boilers.

III. ELECTRO-MAGNETIC RAILWAY TRAIN CONTROLLER.

192. This apparatus is the invention of Messrs. Wright and Bain, the latter of whom is already well known as the inventor of the electro-magnetic printing telegraph, the electrical clock, &c. From the models and diagrams exhibited at the Polytechnic Institution, it appears that the invention consists in the conveyance of the electric fluid from a battery to be placed in the locomotive engine by which the train is drawn, to a *pilot* locomotive engine by which the former is to be preceded on the railway at the distance of about a mile and a half. If, therefore, any obstacle occur on the railroad, by which the pilot locomotive is stopped or disturbed in its course, the communication through the electric fluid will be broken, and ocular notice by means of an index attached to the locomotive engine of the train will be immediately given to the engine driver to put on the breaks and stop the train. Should no attention be paid to the index, the apparatus on the locomotive of the train in connexion with the wires extending to the pilot, will cause a gong to be struck, and thus convey further warning; and, should this be neglected, the apparatus will cut off the steam of the locomotive of the train, apply the breaks, and thus, without the interference of the engine driver, prevent the train from proceeding. The electric fluid is conveyed from one locomotive to the other by means of wires laid between the rails of the railroad, which wires are constantly in contact with the locomotive engines by means of feelers, which descend from the locomotive engines and pass along the surface of the wires. According to the miniature exhibition of the models of the machines, the invention is conclusive as to safety and efficacy; but whether it would be equally successful in actual operation, it is impossible at present to say. The wires are not affected, as conductors of the electric fluid, by wet or damp.

This fact has been ascertained at the above Institution, by passing them through the tank, and then communicating the fluid.

IV. OF ROTARY ENGINES.

193. *Object of Rotary Engines.*—It occurred to Watt that, in cases in which motions round an axis are required, as in workshops and manufactories, steam vessels might be constructed in the form of hollow rings or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles, like the wheels of a water mill. By such an apparatus it was proposed to dispense with all the machinery which, in the common steam engine, is interposed between the steam and the axis of motion, for the purpose of converting the alternate rectilinear into the circular motion, as the cylinder and piston, the beam, and the crank. It was thought that a loss of power is sustained by the use of the crank, and that a circular motion, accompanied with the development of the greatest power, might be at once produced, by causing the steam to act *immediately* upon projections on the circumference of the wheel, and to follow it throughout its entire revolution.

194. *Objections to Rotary Engines.*—Mr. Scott Russell has pointed out the fallacy of this project. In a paper which appeared in the Transactions of the Scottish Society of Arts, he states that, in *theory*, the ordinary crank has not the defects usually attributed to it, and which it is the sole object of the rotary engine to remedy—"because, 1, the velocity of the crank is in the inverse ratio of the pressure upon it; because, 2, the mean pressure on the crank during the whole revolution is less than the pressure on the piston, only in the proportion in which the whole space moved over by the latter is less than the space described by the former, so that the whole effect is equal to the whole power; because, 3, the steam is not at all expended at the neutral points, and because its expenditure is at every point exactly

proportioned to the pressure which it gives out, the velocity of the piston being in that ratio." Again:—"In a *practical* point of view, it may be shown, that the rotary steam engine is greatly inferior to the common reciprocating crank engine in simplicity of parts, easy construction, precision and uniformity of work, and durability and economy in use; and that it does not possess any of the peculiar applicability that has been attributed to it, to the great purposes of inland navigation and railway transport."

195. *Classification of Rotary Engines.*—Mr. Russell distinguishes rotary engines into four classes:—

1. Rotary Engines of Simple Emission.
2. Rotary Engines of Medial Effect.
3. Rotary Engines of Hydrostatical Reaction.
4. Rotary Engines of the Revolving Piston.

1. The *first class* of rotary engines may be illustrated by the machines of Hero and Branca (pp. 20, 21). On these, Mr. Russell observes, that "there is no possibility of obtaining, by *simple emission*, in the most favourable circumstances imaginable, more than one-half of the whole power of the steam, so as to make it available to useful mechanical effect. The other half is wasted in giving off its impulsion to the air, or is expended in a current equally unavailing. 2. The *second class* of rotary engines of *medial effect* are those which do not immediately give revolution to an axis, by the action of steam upon a wheel, but have a medium of communication between the power and the effect, which medium is the direct agent in circular motion. This class of engines will be well understood, by taking as its type any simple steam machine, such as Savery's or Newcomen's, used for raising water; which water, by falling on the floats of a common mill wheel, will then give rotary motion to it. In this class of engines, the loss of effect is manifest; for it is necessary that the steam, in order to produce the circular motion, shall give out its force in setting the medium in motion, and in overcoming the very great resistance of the liquid in all the pipes and passages and valves, through

which it is transmitted to alternate sides of the wheel in every revolution. The force thus subtracted from useful effect, is power lost." 3. In the *third class* of rotary engines of *hydrostatical reaction*, the principle of action is as follows:—"Steam is admitted into a circular channel, or chamber, on the circumference of a wheel. This chamber is partially filled with some liquid; the pressure of the steam is expended in pushing the mercury in one direction, and the end of the chamber in the opposite way; so that, while the liquid is thus forced out of the chamber, the chamber is by an equal force pushed away from the liquid. The wheel is thus moved round. It is apparent that a part of the force is employed in propelling the wheel, and the remainder is expended in overcoming the resistance of the liquid of reaction, and expelling it from the chambers, which remainder is a large portion of the power withdrawn from useful effect." 4. In the *fourth class* of rotary engines of the *revolving piston*, "the steam is confined in a close and rigid chamber, and acts only on solid inflexible surfaces, and escapes along confined passages, so that its full effect may be obtained in useful work. Abstractedly considered, it is an engine capable of giving out the full power of the steam, and, therefore, may fairly be imagined to come into competition with the ordinary reciprocating crank engine. The objections to it are entirely of a practical nature, and regard the engine, not in its abstract mathematical form, but as a machine made of destructible matter—of matter imperfectly elastic—of surfaces offering resistance to motion—of matter obeying the known laws of motion and rest."

THE END.

APPENDIX II.

REPORT OF SIR W. EDWARD PARRY AND MESSRS. EWART AND LLOYD ON HALL'S CONDENSERS.*

196. In pursuance of Sir George Cockburn's minute of the 19th of February, 1842, on the statement accompanying Mr. Samuel Hall's note of the 7th of February, we beg leave to submit the following Report, founded upon all the information which could be obtained respecting the results of the application of Hall's Condensers to vessels not in her Majesty's service; and upon consideration of the present condition of the condensers of the "Megæra," and the effects which this system of condensation appears to have produced with regard to the consumption of fuel, and the condition of some parts of her engines and boilers.

Having understood that Hall's Condensers had been tried in several steam vessels belonging to the St. George's Company, and subsequently removed from them, Commander Bevis was directed to make special inquiry as to the circumstances attending such removal. By Commander Bevis's report of the 10th of March (enclosed herewith), it appears that these condensers were applied to six vessels, and removed from them after a trial varying from two to six years, in consequence, as it is alleged, of their complicated construction, and the difficulty of keeping them in order. This is entirely at variance with the experience afforded by the "Megæra" during a trial of four years, during the last three years of which the condensers were not even opened for inspection, and they are now in good condition. The Report of the Engineer Officers of Woolwich Yard, dated 11th of March, transmitted herewith, is conclusive on this point.

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* This Appendix, recently furnished to the Author by favour of the Lords Commissioners of the Admiralty, completes the Reports of Mr. Samuel Hall's Condensers, *literally*, to the present day, and forms a continuation of the subject introduced into the body of the work. See pp. 211—231.

Although in ordinary cases the vacuum is better with Hall's condensers than with those of common construction, it is necessary to state that we have been informed that in tropical climates, where the temperature of the sea water used for condensing the steam is high, the process of condensation is less perfectly performed by Hall's condensers than by the common ones. An application has been made to the East India Company to furnish any facts which might throw light on this part of the subject, but they do not at present possess the required information. If, however, this difficulty should be found to exist in a tropical climate, we think it probable some means of obviating it might be devised.*

To ascertain the saving of fuel, we have made a comparison between the consumption in the "Megæra" and the "Volcano." The boilers of the "Volcano" are of copper, and those of the "Megæra" are of iron, with Hall's condensers; in other respects the vessels are alike.

From the accompanying account it will be seen that the average daily consumption of fuel on board these vessels has been obtained in two ways, perfectly distinct from each other:—

First, by ascertaining from the logs of the respective vessels the number of days on which the engines were at work, and comparing it with the total quantity of fuel expended;

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* In reply to the statement respecting defective condensation in tropical climates, may be adduced the counter-statement of a practical engineer, whose testimony has been already furnished on this subject (p. 226). Mr. Lambert says, "I am astonished to find, on my return from India, that the patent engines are not universally adopted, *especially for hot climates, where they obtain an extremely superior vacuum.*"

Secondly, by taking an average of the consumption of fuel per horse power per hour, as reported by the commanders in the monthly returns.

The average daily consumption in the

Megæra was, by the first mode	.	$14\frac{5}{7}$	Tons
,, ,, second mode	.	$13\frac{41}{56}$	,,
Mean .	.	$14\frac{1}{2}$	,,
Volcano was, by the first mode	.	$17\frac{13}{60}$	,,
,, ,, second mode	.	$18\frac{4}{5}$	,,
Mean .	.	18	,,

showing a saving per day of 3½ tons, or nearly 20 per cent.; or if, as an approximation, the vessel be supposed to run 150 days in the year, and the cost of the coal be estimated at 20s. per ton, the saving in the cost of coal would amount to £525 per annum.

The comparative consumption of fuel in these two vessels could not materially differ from what is here given, but we are not prepared to say that this great saving is entirely to be attributed to Mr. Hall's condensers. Some part might have arisen from the commanders constantly evincing a strong desire to economize the fuel, and from the care and judicious management of the engineer. A considerable saving, however, must, we think, always obtain from there being no necessity for blowing out at short intervals a part of the boiling water, from there being no incrustation within the boiler to impede the transmission of heat, and from the necessity which this system of condensation induces to prevent, as far as possible, any waste of steam, as its place must be supplied by fresh water produced by distillation from salt water.

No account can be rendered of the comparative cost of repairs in these two vessels, in consequence of the repairs being performed by contract, and of the boilers of the "Volcano" being made of copper; but considering that the whole of the internal parts of the boilers of the "Megæra" are now perfectly good, which, when salt water is used in iron boilers for an equal length of time, is never the case, and that the condition of some parts of the engines is certainly better than if salt water had been used, we think we should not estimate too highly the annual saving in repairs at £150, which with the estimated value of the saving in fuel, would amount to £675.

The first cost of the patent condensers, according to the statement of Messrs. Seaward and Capel, is from £7 to £8 per horse power; according to Mr. Hall, it is from £5 to £10 per cent. upon the cost of engines and boiler, or from 2½ to £5 per horse power.

In conclusion, it may be remarked that Hall's Condensers are calculated to enable a vessel to run without repairs for a longer time than common condensers; but to what extent, we have not had sufficient experience to enable us to state with any degree of certainty.

W. E. Parry.
P. Ewart.
T. Lloyd.

The Author is enabled to state that the Lords Commissioners of the Admiralty have contracted with Mr. S. Hall for the application of his condensers to the Admiralty steam yacht, the "Black Eagle,"—in consequence, doubtless, of the satisfaction caused by the successful performance of the "Megæra."

May 2, 1842.

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